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Bedrock and Surficial Geology of the McConnellsburg Quadrangle, Pennsylvania

Kenneth L. Pierce

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ATLAS 109a

Bedrock and Surficial Geology of the McConnellsburg Quadrangle, Pennsylvania

by Kenneth L. Pierce

Cooperating Geologist

Pa. Geological Survey

PENNSYLVANIA GEOLOGICAL SURVEY

FOURTH SERIES

HARRISBURG

1966

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Gaps and sags along the ridge crests generally correlate with cross faults or cross folds. Placement by faulting of the more resistant Tuscarora Sandstone against shale seems to be more important for gap formation than structural weakening by faulting. No evidence of weakening is present in the Rocky Hollow Gap. Township Run is locally superposed across the Tuscarora Formation.

The Kittatinny and Harrisburg "peneplains" may be part of the normal topography developed during single-cycle erosion on the given bedrock.

INTRODUCTION

This report was originally submitted to Yale University as a Ph.D. dissertation (Pierce, 1964) and is presented here with some revision. Description of the geology of the McConnellsburg quadrangle is presented in two major parts—Part 1, Bedrock Geology and Part 2, Surficial Geology and Geomorphology. Field work upon which this report is based was carried out during the summers of 1961 and 1962 with support of the Pennsylvania Geological Survey.

The McConnellsburg quadrangle is located in the eastern part of the Valley and Ridge physiographic province in southern Pennsylvania (Figure 1) and includes parts of Franklin and Fulton Counties. The area covered by the McConnellsburg quadrangle covers $7\frac{1}{2}$ minutes of latitude and longitude and measures 8.5 miles from north to south and 6.6 miles from east to west. The topographic map covering the area was prepared by the U. S. Army Map Service and was released by the U. S. Geological Survey at a scale of 1:24,000.

PREVIOUS WORK

Prior to this report, the most detailed geologic report on this area was the Mercersburg-Chambersburg Folio (map scale 1:62,500) by G. W. Stose (1909), which covered the equivalent of eight $7\frac{1}{2}$ -minute quadrangles. In general, Stose's map is a good representation of the geology of the area, although in some places locations of stratigraphic units and structures appear to be in error. The present study, on a larger scale base, uses a stratigraphic section with almost twice as many units as that of Stose (1909). More important, this report gives much description not included in Stose's report and conclusions that differ from his.

Others have studied the geology in the quadrangle. H. D. Rogers was the first to describe the geology of Pennsylvania extensively, and he included in his final report (1858) detailed descriptions of some aspects of structure and stratigraphy of rocks within the McConnellsburg quadrangle. In the Second Survey of the state, Fulton County was ably mapped by J. J. Stevenson (1882) on a very poor base map at a scale of 1:126,720. E. V. d'Invilliers (1887) reported on the iron mines of the area, and Frazer (1877) drew some cross sections across Franklin County.



In recent years, students from the City College of New York have done field mapping in the area.

Rocks within or near the quadrangle have been described recently in the following regional stratigraphic studies: Conococheague Formation by Wilson (1952), Beekmantown Group by Sando (1957) and Hobson (1957; 1963), Saint Paul Group by Neuman (1951), Martinsburg-Reedsville Formation by McBride (1960; 1961), sandstones of the Taconic clastic wedge by Yeakel (1962), Bloomsburg Formation by Hoskins (1961), and part of the Acadian clastic wedge by McIver (1961).

TOPOGRAPHY AND DRAINAGE

All streams in the area drain eventually into the Atlantic Ocean via either the Potomac River or the Susquehanna River. The drainage divide between the Atlantic Ocean and the Gulf of Mexico lies approximately 40 miles west of the quadrangle, near the eastern edge of the Allegheny Plateau (Fig. 1). Conococheague Creek, the main stream in the Cumberland or Great Valley in southernmost Pennsylvania, flows south into the Potomac River. The West Branch of Conococheague Creek (hereafter referred to as West Branch) drains the Mercersburg reentrant of the Great Valley and the valleys adjoining this reentrant, which are: on the north, the southern part of Path Valley; on the northeast, Bear Valley; and on the west, the small valleys heading near Buchanan Summit.

Cove Creek heads in McConnellsburg Cove and flows south within the Valley and Ridge province to the Potomac River. Allen Valley drains north by way of Aughwick Creek into the Juniata-Susquehanna River system. Conodoquinet Creek heads on Jordans Knob, flows north through Horse Valley, and eventually enters the Susquehanna River at Harrisburg.

Within the McConnellsburg quadrangle, the larger streams generally flow parallel to the northerly strike of ridges of Tuscarora Sandstone, at altitudes ranging from 600 to 1,500 feet. Streams flowing along structural synclines (Aughwick Creek, Conodoquinet Creek, Buck Run, and Rocky Hollow) occupy scenic timbered valleys more than 1,000 feet in altitude. The streams on shale and carbonate rocks in breached anticlines flow through open, farmed valleys at lower altitudes.

Smaller, first-order streams flow across strike in steep valleys and enter the main streams at nearly right angles.

Elongate, nearly level-crested, strike ridges of Tuscarora Sandstone at altitudes of about 2,000 feet form the prominences of the area, rising as much as 1,000 to 2,000 feet above the valley bottoms. Following are the names of ridges, from east to west, in or near the McConnellsburg quadrangle. Parnell Knob, in the core of a north-plunging syncline just east of the quadrangle, separates northward into First Mountain on the east

and North Mountain on the west. Similarly, Jordans Knob, in the core of another north-plunging syncline near the eastern edge of the quadrangle, separates northward into Little Mountain on the east and Kittatinny Mountain on the west. Striking diagonally across the center of the quadrangle is a highland area made up of two to three ridges. North of Highway U. S. 30, Tuscarora Mountain is the eastern continuous ridge; south of the highway it is considered to be the western ridge. Conversely, north of Highway U. S. 30, Cove Mountain is the western ridge, whereas south of the highway it is the eastern ridge. According to topographic nomenclature, these two ridges cross each other in the middle of the quadrangle. Big Mountain, elevation 2458 feet, is the highest point in the area, and lies along the anticlinal crest of Tuscarora Mountain in the middle of the quadrangle. On the northwest side of McConnellsburg Cove is Little Scrub Ridge with an unusually irregular crest.

Details of the relation of topography to lithology and structure of bedrock are discussed in the section on topography at the end of this report.

ACKNOWLEDGMENTS

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Grateful acknowledgment is expressed to Donald M. Hoskins who assisted with evaluation of the bedrock geology during two visits in the field. John T. Hack is likewise thanked for assistance in the study of surficial deposits, contributing by a two-day field visit and by critical evaluation of the discussion on transported regolith. Appreciation is expressed to the following persons who aided by discussion and criticism of parts of the work: Richard L. Armstrong, John Ostrom, Gordon Wood, Paul Enos, my wife Linda, and my father William G. Pierce.

Faculty advisors Richard F. Flint, and John Rodgers of Yale University helped initiate this Ph.D.-thesis study and have followed it to completion with field visits, discussions, and extensive criticisms of the manuscript which have improved greatly the value of the study.

PART 1—BEDROCK GEOLOGY

STRATIGRAPHY

The bedrock exposed within the McConnellsburg quadrangle ranges from the Upper Cambrian Conococheague Group to Upper Devonian Catskill-Brallier transition beds. Within this interval, Upper Silurian

to Middle Devonian sedimentary rocks are faulted out, but probably underlie Upper Devonian clastic rocks in the northwest corner of the quadrangle. Upper Cambrian to Middle Silurian sedimentary rocks total 8,500 feet in thickness and are divided into 14 formations, some of which contain member subdivisions. Upper Devonian rocks are 5,500(?) feet thick and are described in three units. A columnar section with condensed stratigraphic descriptions forms the explanation to Plate 1.

In this account, the formations are divided into five litho-genetic groups. For each group, a sketch of the source area and depositional environment follows the separate group description. This organization makes possible a more meaningful synthesis than does the traditional subdivision by geologic periods, for the period boundaries here do not represent significant changes in the depositional history.

The formations are defined entirely on a basis of rock character. Considered regionally, most of them are time-transgressive units. The vertical succession of sedimentary rocks can be explained largely as the lateral migration of a complex of contiguous sedimentary environments or facies forward and backward across the area of the quadrangle as the region slowly subsided. The sedimentary rocks are of the miogeosynclinal facies, and contain two clastic wedges derived from orogenic areas to the east.

Within the quadrangle, larger valleys are underlain by Cambrian and Ordovician carbonate rocks, valley flanks and higher valleys by beds of mudrock, and high ridges by beds of Silurian and Ordovician sandstone.

CAMBRIAN AND ORDOVICIAN CARBONATE ROCKS

Carbonate rocks ranging from Upper Cambrian Conococheague limestone to Middle Ordovician Salona Formation are exposed within the quadrangle. These rocks constitute the upper 3,500 feet of a section of Lower Cambrian to Middle Ordovician carbonate rocks 9,000 feet thick, exposed nearby. Upon weathering, these rocks form residual Hagerstown soils (Higbee and others, 1938; unpublished maps of the Soil Conservation Service, McConnellsburg, Pa.).

Conococheague Group (upper part)

Name—The Conococheague Formation was named by Stose (1908, p. 701; 1909, p. 6) for exposures along Conococheague Creek, 25 miles east across strike from McConnellsburg. The unit was recently raised to group rank (Geyer and others, 1963, p. 29). In a regional stratigraphic study J. L. Wilson (1952, p. 311-312) described a measured section of the upper part of the Conococheague just south of McConnellsburg.

Outcrop belts and thickness—The upper part of the Conococheague Group is exposed in the crest of the McConnellsburg Cove anticline

where it underlies open rolling farmlands. A few ledges crop out in the fields, but normally the formation weathers to a productive soil with blocks of predominantly light-colored chert. Just west of the quadrangle, in the core of the McConnellsburg Cove anticline, the sandy zone of the upper Gatesburg member supports a low wooded ridge.

On the east limb of the McConnellsburg Cove anticline, the Conococheague beds overlying the Gatesburg dolomitic sandstone member measure 360 feet in thickness. This represents only the upper quarter of the total thickness of the Conococheague Group.

Character—Although the upper part of the Conococheague Group contains many kinds of carbonate rocks, it is characterized by wavy but continuous beds of bluish-gray-weathering lime-mudstone a quarter to a half inch thick separated by equally thick seams of light-brown-weathering, silty dolostone. Stratification planes of this rock type display mud cracks, ripple marks, and burrows. Local edgewise conglomerates are composed of slightly deformed limestone disks in a calcareous matrix. Beds of gray, white-weathering dolostone a few feet thick comprise an estimated 20 percent of the upper unit. Beds of massive limestone, oolitic limestone, and cryptozoon limestone, a foot or so thick, are scattered throughout the formation. Medium- and light-gray chert composed of ooliths and nodules of *cryptozoon* is common in the soil but rare in outcrop.

West of the quadrangle, at the contact between upper Conococheague beds and the underlying upper Gatesburg dolomitic sandstone member, the average slope increases and the soil becomes more sandy.

The upper contact of the Conococheague Group with Larke Dolostone is drawn above the highest wavy-banded limestone and below the first dark-gray coarsely crystalline dolostone.

Age—The fauna of the lower part of the upper Conococheague Group in McConnellsburg Cove was reported by Wilson (1952, pl. 3) to be of Trempealeauian age (late Late Cambrian). Sando (1957, p. 16) reported early Ordovician fossils from the upper part of the Conococheague Group in Maryland.

BEEKMANTOWN GROUP

Rocks of the Beekmantown Group (Clarke and Schuchert, 1899, p. 877) crop out in the Mercersburg reentrant and in McConnellsburg Cove. This group was divided into three formations by Sando (1957) in Maryland, four formations by Ulrich (1911, Pl. 27) in central Pennsylvania, and four formations by Hobson (1957; 1963) in eastern Pennsylvania. Because of poor exposures within the quadrangle rocks of the Beekmantown Group can be compared to these other subdivisions only tentatively. The Larke, Nittany, Rockdale Run, and Bellefonte Formations are mapped.

Larke Formation

Name—The Larke Formation was named by Butts (1918, p. 527) for exposures of a dark-gray dolostone near Larke, Blair County, on the Nittany arch 30 miles north-northeast of McConnellsburg.

Outcrop belts and thickness—The Larke Dolostone crops out south of McConnellsburg where it underlies low hilly farm-lands. This unit measures 450 feet in thickness half a mile south of McConnellsburg.

Character—The Larke Dolostone consists mostly of medium-bedded, coarsely crystalline, dark-gray dolostone. In places this dark-gray dolostone is laced with seams and pods of white dolomite. Medium- to light-gray dolostone constitutes as much as one-quarter of the formation.

The upper contact is gradational and is drawn where medium- and light-gray dolostone predominate over dark-gray dolostone.

Age—The Larke Dolostone is probably of early Ordovician age. Because the upper part of the underlying Conococheague Group contains Early Ordovician fossils in Maryland, as reported above, the Larke Dolostone is probably not of Late Cambrian or earliest Ordovician age.

Nittany Formation

Name—The Nittany Formation was named by Ulrich (1911, Pl. 27) for exposures near Nittany, 80 miles north-northeast of McConnellsburg. These rocks are also stratigraphically and lithologically similar to the Rickenbach Formation (Hobson, 1957), named for exposures in eastern Pennsylvania.

Outcrop belts and thickness—The Nittany Dolostone crops out in the vicinity of McConnellsburg. Its outcrop belt is normally covered by deep residuum containing light and dark chert with nodular, scoriaceous and *cryptozoon* forms.

The Nittany Dolostone is about 1,400 feet thick on the west side of the McConnellsburg Cove anticline; it appears to be only 1,000 feet thick on the east side of the anticline and may be partially faulted-out there.

Character—The Nittany Formation consists of light- to dark-gray, finely to coarsely crystalline dolostone. The beds are about 6 inches thick and are generally massive, except for a zone near the top of thicker bedded, light-gray, laminated dolostone similar to the Bellefonte Dolostone. Some dolomitic quartz sandstone beds crop out near the middle of this unit in McConnellsburg. A breccia consisting of angular blocks of laminated dolostone in a dolostone matrix occurs in the middle of this unit northwest of Cito.

Age—The Nittany Dolostone is of middle Early Ordovician (Canadian) age (Twenhofel and others, 1954).

Rockdale Run Formation

Name—The Rockdale Run Formation was named by Sando (1957, p. 21) for exposures in Maryland, 15 miles southeast of the McConnellsburg quadrangle. Rocks in the quadrangle contain too much dolostone to be considered the Axeman Limestone of central Pennsylvania (Ulrich, 1911, Pl. 27). Apparently the Epler Formation (Hobson, 1957, p. 2720; 1963, Fig. 18) is lithologically and stratigraphically equivalent to the Rockdale Run Formation within the quadrangle.

Outcrop belts and thickness—In the Mercersburg reentrant the Rockdale Run Formation crops out in the southeastern corner of the quadrangle and at the base of Cove Mountain. In McConnellsburg Cove only two outcrops of Rockdale Run limestone were observed within the quadrangle, but just west of the quadrangle a rather thick section is apparently present. The Rockdale Run Formation is either faulted out, greatly thinned, or absent in the core of McConnellsburg Cove anticline both near the northern boundary of the quadrangle, and south of McConnellsburg on the east side of the anticline. Usually, its outcrop trace is covered by deep cherty residuum but in the Mercersburg reentrant along the base of Cove Mountain it is covered almost completely by sandstone debris from nearby mountains.

In the southeast corner of the quadrangle, rocks tentatively assigned to the upper part of the Rockdale Run Formation measure 600 feet in thickness. In McConnellsburg Cove this unit may range from 0 to 1,000 feet in thickness.

Character—In the *Mercersburg reentrant* two outcrop belts of the upper part of the Rockdale Run Formation are mapped. A quarter of a mile south of the quadrangle, near the road along the base of Cove Mountain, there are a few outcrops of interbedded limestone and dolostone including a bed of black chert. Some of this limestone is "tiger striped"* with seams of dolomitic limestone.

Along West Branch just west of the fault in the southeastern corner of the quadrangle is a well-exposed section of thick-bedded limestone and dolostone. The limestone consists of dark-gray lime-mudstone, "tiger striped" limestone with dolomitic seams, and some lime-sandstone. It contains more impurities than does the Middle Ordovician Saint Paul Limestone. The dolostone is medium- to light-gray and in massive planar beds. Although these rocks were assigned to the Rockdale Run Formation, their interpretation as a slightly different facies of the Saint Paul Limestone was not considered impossible. However, their assignment to the Saint Paul Limestone results in a much simpler structural interpretation than assignment to the Rockdale Run Formation. R. B. Neuman

* Defined under "Saint Paul Limestone" below.

(written communication, 1963) examined a few fragmentary fossils from these rocks and considered a lower Ordovician (Rockdale Run) correlation more likely.

In *McConnellsburg Cove* only two exposures of Rockdale Run limestone were noted within the quadrangle. Limestone with mottled dolomitic bands was quarried in the eastern part of the town of McConnellsburg. A partially exposed section of interbedded limestone and dolostone apparently of the Rockdale Run Formation crops out west of the quadrangle in a quarry and on the hills to the west, on the west side of U. S. Highway 522, 0.7 miles south of McConnellsburg. Some of these limestone beds are crudely "tiger striped."

The upper contact is drawn at the top of the uppermost limestone of the continuous interbedded limestone and dolostone sequence and at the base of the monotonous Bellefonte Dolostone. A few isolated limestone beds may be present above the contact. Probably, the mottled dolostone referred by Sando (1957, p. 22) to the upper part of the Rockdale Run Formation is included here in the Bellefonte Dolostone.

Age—At the nearby type locality the Rockdale Run Formation is of middle Early Ordovician age (Sando, 1957, Pl. 3).

Bellefonte Formation

Name—The Bellefonte Formation was named by Ulrich (1911, Pl. 27) for exposures near Bellefonte, 70 miles north of the quadrangle. At least the upper part of the Bellefonte Dolostone, as mapped, is lithologically equivalent to the Pinesburg Station Dolostone (Sando, 1957, p. 28), which was named for exposures along the Potomac River.

Outcrop belts and thickness—Bellefonte Dolostone crops out near the crest of the McConnellsburg Cove, Foltz, Path Valley, and Bear Valley anticlines. It is more resistant to weathering than the adjacent formations and forms a ridge about 50 feet high and a quarter of a mile wide. Although outcrops are plentiful, it normally weathers to an orange-red residuum. Near the mountains the unit is usually covered with sandstone debris, but may still form a topographic ridge.

The thickness ranges from 850 feet just north of McConnellsburg to 1,000(?) feet in the Mercersburg reentrant.

Character—The Bellefonte Formation is almost entirely light-gray, white-weathering, finely to medium-crystalline dolostone. Much of it is characteristically laminated, but many beds, especially in the lower part, are massive or lightly mottled. The beds are 6 inches to two feet thick. Cross fractures weather on outcrops to form depressions resembling knife slashes. In McConnellsburg Cove, a few beds of dolomitic quartz sandstone 2 to 3 feet thick occur near the top of the formation. A clayey bed, similar to the Middle Ordovician beds of altered volcanic ash, is mapped

at the top of the Bellefonte 3.2 miles northeast of McConnellsburg; the rocks there may be a dolomitic facies of the Saint Paul Limestone or may be incorrectly mapped because limestone beds are not exposed between or below them. Much chert occurs in the residuum. A few hundred feet below the top is a thick zone of light chert, including some "cauliflower" chert of Stose (1909, p. 7), but this kind of chert is not always present in this zone nor is it confined to it. Light and dark chert mantle the surface underlain by the lower part of this formation.

As shown by Sando (1957, Fig. 5), the upper contact is gradational and is drawn at the lowest limestone bed above the Bellefonte Dolostone.

Age—The Bellefonte Dolostone is mainly of late Early Ordovician age (Sando, 1957, Pl. 3). The upper part of the Bellefonte may be of earliest Middle Ordovician (Chazyan) age, for the contact with the Saint Paul Limestone is conformable in this area (Sando and Neuman, 1957) and the Saint Paul Limestone is earliest Middle Ordovician in age. (See discussion of age under "Saint Paul Limestone" below.)

Saint Paul Group

Name—Neumann (1951, pp. 278-279) named the Saint Paul Group for exposures near Saint Paul Church, Maryland, 15 miles south-southeast of the quadrangle. As discussed in Neuman (p. 269-276), earlier reports have included these rocks in the Stones River Limestone.

Outcrop belts and thickness—The Saint Paul Group is mapped separately where it crops out on the flanks of the Foltz, Path Valley and Bear Valley anticlines. Because of poor exposures in McConnellsburg Cove, it was necessary for mapping purposes to combine the Saint Paul with the overlying Chambersburg Limestone. The Saint Paul limestone is readily soluble and underlies lowlands below the adjacent carbonate units. It weathers to a chert-free, reddish-brown clayey soil. Well out in the larger valleys the Saint Paul crops out enough to permit detailed mapping, but usually in areas within a mile of the sandstone ridge crests the outcrop trace is completely covered with sandstone debris.

Outcrops of the Saint Paul Group are rare except in the southeastern corner of the quadrangle; some isolated but significant exposures are located as follows: 1) beneath a thick blanket of sandstone debris in Reese Cave in the southeastern part of Dutchtown, 2) in caves and quarries 1¼ miles east-southeast of Cowan Gap, 3) at the locality of the measured section of the Chambersburg Limestone in McConnellsburg Cove, and 4) in abandoned quarries 6,400 feet N 10° W of McConnellsburg.

In the southeastern corner of the quadrangle the Saint Paul Group is 560 feet thick, but east of Cowan Gap it apparently thins to 250 feet, and two miles north of McConnellsburg is locally only 170 feet thick

(faulted?). This zone of thinning trends through the northwestern part of the quadrangle and is apparently an extension of the Middle Ordovician Adirondack Axis (Kay, 1951, p. 57; Craig, 1949, Pls. 3, 4, and 6). *Character*—Two rock types characterize the Saint Paul Group and constitute more than 75 percent of it: a gray lithographic lime-mudstone and a “tiger-striped” limestone, so called because on a weathered surface it displays irregular bands half an inch thick of light-bluish-gray lithographic lime-mudstone and light-brown, silty, dolomitic limestone. Beds are generally 1 to 2 feet thick and the bedding surfaces are nearly planar, except for minor channeling. Beds of dolomitic limestone occur in the formation; dolostone beds are common in the basal 200 feet. Thin limestone beds or zones at the bottoms of beds are common but make up less than 10 percent of the formation.

Two subdivisions of the Saint Paul Group, the Row Park and New Market Formations (Neuman, 1951, p. 278, 286), are recognized only at the locality of the measured section in the southeastern corner of the quadrangle. The main lithologic difference between them is that lithographic limestone in the lower part of the New Market is laminated, whereas that in the underlying Row Park is not (p. 284).

A section of 475 feet of interbedded lime-mudstone and dolostone, overlain by 100 feet of lime-mudstone, was described by Stose (1909, p. 7) as exposed in a small gully just south of State Highway 16 almost two miles southeast of McConnellsburg, but it was not observed in the present investigation.

The upper contact with the Chambersburg Limestone is drawn either at the base of the first zone of dark-gray cobbly-weathering limestone or at the base of an interval of lime-sandstone, immediately beneath this cobbly-weathering zone.

Measured section—The New Market Formation of the Saint Paul Group is exposed 400 feet south of the southern boundary of the quadrangle in various quarries on both sides of state Highway 75 and in the wooded pasture to the east. The Row Park Formation is partly exposed in the open pasture farther east, where 75 percent of it is covered and the basal contact with the Bellefonte Dolostone is not exposed. This section is in the northeastern corner of the Mercersburg 7½' quadrangle, about 2,000 feet north of Dickey. The top of the section is 250 feet south of lat. 39°52'30" and 4,900 feet east of long. 77°55'. Here the Saint Paul Limestone is thicker than it is in the McConnellsburg quadrangle.

	<i>Thickness in feet</i>
Chambersburg Limestone	More than
1. Lime-mudstone, argillaceous, dark-gray, irregularly bedded, and cobbly-weathering. (Exposed in northern quarry on west side of State Highway 75. Upper part of Chambersburg Limestone exposed along abandoned railroad cut 0.2 mile south.)	50
2. Lime-sandstone, medium-gray, fossiliferous. (Exposed in shallow pit into natural surface 10 feet east of quarry.)	4

*Thickness
in feet***Saint Paul Group, New Market Formation**

- | | |
|---|-----|
| 1. Lime-mudstone, lithographic, medium- to dark-gray, weathers to light-bluish-gray (dove), beds 1 to 4 feet thick. (Poorly exposed on west side of southern main quarry on west side of highway.) | 75 |
| 2. Lime-mudstone, medium- to light-gray, weathers bluish-gray, beds 1 to 3 feet thick. Either finely laminated or "tiger-striped." In upper 50 feet calcite pods characterize beds of "birds-eye" limestone. Cyclic deposition in beds 1 to 3 feet thick is rather common, with channeling and lime-sandstone at bottom of bed. Deformed laminae indicate slumping; mud-cracks indicate dessication. Some algal mounds. About 10 percent dolomitic limestone. Also irregular partial dolomitization indicated by mottling and "tiger stripes." A shaly zone 4 inches thick 145 feet below the top of the New Market Limestone is similar to the altered volcanic ash beds of the Chambersburg Limestone. (Exposed in main quarries on east and west side of highway and for 800 feet to east across entire wooded pasture to fence line. Minor anticline probably repeats 70 feet of section 200 feet west of fence line. Altered volcanic ash beds exposed on west face of main quarry on east side of highway.) | 290 |

Total New Market Formation	365
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Saint Paul Group, Row Park Formation

(Scattered outcrops in open pasture east of quarries and wooded pasture.)

- | | |
|---|-----|
| 1. Lime-mudstone, lithographic, medium- to light-gray, beds 1 to 2 feet thick. Some beds of dolomitic limestone. No laminations. "Tiger-striped" banding subdued. | 50 |
| 2. Interbedded medium-gray lithographic limestone, dolomitic limestone and light-gray dolostone. Amount of dolostone increases towards the base. Some beds of lime-sandstone and breccia. | 150 |

Total Row Park Formation	200
--------------------------	-----

Bellefonte Dolostone

(Exposed on low ridge to east and in stream banks at Dickey to south.)

- | | |
|--|-----------------|
| 1. Dolostone, light-gray, medium- to coarsely crystalline; some beds laminated but most massive with subdued mottling. | more than
75 |
|--|-----------------|

Age—Neuman (1951, Fig. 42), concludes that the Row Park is of middle and late Chazyan age and that the New Market is of Pamelaia age; accordingly, the Saint Paul Group is of early Middle Ordovician age.

Chambersburg Formation

Name—The Chambersburg Formation was named by Stose (1908, p. 710) and later described more completely by him (1909, p. 9) in the Mercersburg-Chambersburg Folio. The definition of the Chambersburg Formation used in this report conforms with Stose's usage at most localities given in the folio except of the section at Marion, which has subsequently been considered to be the type section, but which was measured and subdivided by E. O. Ulrich and Stose largely on a basis of Ulrich's paleon-

tologic work. Later authors revised the Marion section (see Cooper and Cooper, 1946, p. 55-58; Craig, 1949, p. 711-714 and section 27). Craig (1949) subdivided the Chambersburg Limestone into two formations and five members, but these subdivisions are not clearly recognizable within the quadrangle, and even if they were, most of them would be too thin to be shown on the map.

Outcrop belts and thickness—The Chambersburg Limestone underlies three outcrop belts in the Mercersburg reentrant, tracing out the north-plunging Horse Valley syncline and the south-plunging Path Valley anticline. On the east side of McConnellsburg Cove it underlies a narrow band along the lower mountain flank. Where the outcrop trace is within one mile of the sandstone ridge crests it is normally covered with sandstone debris. At greater distances from the ridge crests the Chambersburg Limestone may crop out, but usually it is weathered to a shaly residual soil that contains zones of distinctive dark-gray cobbles of limestone. In McConnellsburg Cove the thinness of the Chambersburg Limestone coupled with the almost complete cover of sandstone debris prevented its being mapped as a separate unit.

The thickness of the Chambersburg Limestone decreases from east to west across the quadrangle and is as follows: (1) 260 feet near Dickey in the southeast corner of the quadrangle (Stose, 1909, p. 8; Craig, 1951, section 13), (2) 200 feet south of Fort Loudon (Stose, 1909, p. 8), (3) 200 feet east of Cowan Gap, and (4) 85 feet 2 miles north of McConnellsburg (see measured section). This thinning is toward the Adirondack axis (Kay, 1942, p. 1629; Craig, 1949, p. 749-750) which trends northeasterly through the Path Valley-McConnellsburg Cove region; the rocks are reported to thicken again to the northwest.

Character—The Chambersburg Formation is characterized by irregular beds of dark-gray argillaceous limestone 1 to 4 inches thick. Upon weathering, these irregular beds produce a large number of cobbles of bluish-gray limestone speckled with white calcite. The irregular surfaces of the cobbles display many concavities. In freshly plowed fields the cobbles form a distinctive "conglomerate" or diamicton. Formation of cobbles is facilitated by clayey partings along irregular cleavage planes at an angle to bedding.

Although zones of cobbly-weathering limestone about 20 feet thick are diagnostic of Chambersburg Limestone and by definition form its basal beds, they constitute only about half the formation. Most of the rest of the formation consists of gray planar-bedded lime-mudstone and, less commonly, lime-sandstone, both in medium to thick beds (0.1 to 2 feet) which form zones 20 to 40 feet thick. Twelve beds of altered volcanic ash ("metabentonite") were recognized by Craig (1949, p. 718, 731) in equivalent rocks.

Craig (1949) placed a number of regional unconformities in the section, but no evidence of such unconformities was observed in the limited exposures within the quadrangle, although changes in the rate of deposition are probably indicated by the thinning over the Adirondack axis in the western part of the quadrangle.

The upper contact of the Chambersburg Limestone is drawn at the top of the highest medium- or light-gray limestone and at the base of planar-bedded black argillaceous limestone and black calcareous shale of the Salona Formation.

Measured sections—Just south of the quadrangle and northeast of Dickey, Craig (1949, section 13) measured and described a section of the Chambersburg Limestone 260 feet thick (Pinesburg and Shippensburg Formations). He noted 75 feet of cobbly-weathering limestone overlain by a 200 feet of alternating zones about 20 feet thick of dark-gray irregular- and thin-bedded, slightly cobbly-weathering limestone and light- to dark-gray, planar- and thick-bedded lime-mudstone.

In McConnellsburg Cove in a gully behind the Pepper chicken farm (14,250 feet south of lat. 40° and 6,950 feet east of long. 78°, or 11,550 feet N 34° E of McConnellsburg), the upper part of Saint Paul Group, the Chambersburg Limestone, and the Salona Formation are exposed. The lower part of the Saint Paul and its contact with the underlying Bellefonte Dolostone probably underlie the fields a few hundred feet east of U. S. Highway 522. Only 35 percent of the Chambersburg Limestone is covered. The upper third of the Saint Paul Group is almost continuously exposed, but the lower part is 80 percent covered.

	<i>Thickness in feet</i>
Salona Formation	
1. Interbedded grayish-black argillaceous planar-bedded limestone and grayish-black calcareous shale. Both lithologies are carbonaceous. Beds are 4 inches to 4 feet thick. Shale content increases up section. (Top of section near small water-supply dam.)	20
2. Covered, float similar to #1.	15
3. Exposed, same as #1.	30
4. Mostly covered, float and scattered outcrops same as #1.	29
Chambersburg Formation	
1. Limestone, light-brownish-gray, coarse-grained, thick-bedded. Highly veined with white calcite and has marble-like aspect. (Crops out in southernmost gully.)	14
2. Limestone, argillaceous, dark-gray, irregularly bedded and cobbly-weathering. Typical Chambersburg Limestone.	18
3. Mostly covered. Scattered exposures of medium-gray limestone. (Traverse offset 40 feet to northeast.)	20
4. Limestone, dark-gray, argillaceous, irregularly bedded. Weathers to light-bluish-gray cobbles. Fossiliferous.	18
Total Chambersburg Formation	70
Saint Paul Group	
1. Limestone, aphanitic, medium- to light-gray, planar-bedded, weathers bluish-gray. Some seams of dolomitic limestone. (Measured in east end of westernmost sink.)	19
2. Limestone, "tiger-striped," light- to medium-gray, thick-bedded.	26

	<i>Thickness in feet</i>
Beds 1 to 4 feet thick. Some laminated limestone and dolomitic limestone beds. (Measured in westernmost sink, behind chicken house.)	
3. Covered. (Traverse 50 feet southwest along strike.)	55
4. Interbedded light-gray lime-mudstone and dolomitic limestone. At top, bed of "tiger-striped" limestone 3 feet thick. (Large out-crop beneath water well and pump in farmyard.)	21
5. Covered. (Traverse 50 feet to northeast along strike.)	3
6. Limestone, "tiger-striped."	1
7. Covered.	36
8. Lime-mudstone, medium-gray.	0.5
9. Covered.	5
Total Saint Paul Group	166.5

Bellefonte Formation

1. Dolostone, medium- crystalline, medium- to light-gray. 4
2. Scattered float and outcrops of dolostone through a horizontal distance of 470 feet across strike to U. S. Highway 522.
(Traverse intersects highway 100 feet north of entrance to Peffer chicken farm, and 100 feet north of F. E. Co. Pole #1005.)

Age—The Chambersburg Limestone was considered by Craig (1949, Pl. 2) to be of Bolarian (Black River?) and Trentonian age; accordingly, it is of middle Middle Ordovician age.

Salona Formation

Name—The Salona Formation was named by Field (1919, p. 420) for exposures at Salona, 50 miles north of the quadrangle. The Salona Formation of this report is similar lithologically and stratigraphically to the Salona Formation in central Pennsylvania as presented by Thompson (1963, p. 19). Craig (1949, p. 738-742) referred rocks of the lower part of the Salona Formation as here used to the Oranda Formation of Cooper and Cooper (1946, p. 86), but the type section of the Oranda Formation is defined largely on a faunal basis, is restricted to only the lower beds of the Salona Formation as here used, and is siltier than the rocks here described. Craig (1949) also referred strata in the upper part of the Salona Formation as here used to the Martinsburg Formation, but the strata in question are very similar to the rest of the Salona Formation, and differ significantly from the overlying lime-poor black shale of the Reedsville (Martinsburg) Formation.

Outcrop belts and thickness—The outcrop belts of the Salona Formation are adjacent to those of the Chambersburg Limestone. The argillaceous limestone and calcareous shale weather to porous shale. Tabular chips of dark-gray punky shale, commonly calcareous, characterize the soil derived from this formation.

The Salona Formation measures about 200 feet thick near Fort Loudon, about 150 feet thick above the sink 1.5 miles southeast of McConnellsb-

burg, and 250 to 300 feet thick 4.7 miles northeast of McConnellsburg. Near McConnellsburg, the Salona Formation appears to be thinned over the Adirondack Axis of Kay (1944).

Character—The Salona Formation consists of interbedded black argillaceous limestone and dark-gray calcareous shale. The bedding surfaces are nearly planar and the beds are generally about 6 inches thick, but may be as much as 3 feet thick. Limestone beds compose about 75 percent of the lower part of the section and progressively decrease in importance to about 10 percent at the top. Many beds of altered volcanic ash ("metabentonite") occur in this part of the section. Craig (1949, sections 7, 8, 11) described 10 to 20 beds of altered volcanic ash in what is here called the Salona Formation (Oranda Formation and basal Martinsburg Shale of Craig) near the quadrangle.

The upper contact with the lower member of the Reedsville Formation is drawn at the top of the highest bed of black limestone that forms part of a continuous sequence containing at least 10 percent limestone beds. The contact is gradational, but easy to locate approximately, for the overlying unit is a distinctive black carbonaceous shale with little or no limestone. The mylonite zone of the Tuscarora bedding-plane fault occurs at this stratigraphic contact and, where exposed, the mylonite is used to map the contact.

Age—The Salona Formation is of Trenton (late Middle Ordovician) age. (See Oranda Formation in Cooper, 1956, p. 82.)

Origin of the Cambrian and Ordovician Carbonate Rocks

Apparently the Cambrian and Ordovician carbonate rocks were deposited in warm, clear, shallow marine water. A low land-mass existed to the northwest. But no land-mass is apparent to the east, except near the end of deposition of the sequence. The major rock types are discussed below. They are not presented in their exact order of deposition, but are in order of their first occurrence.

The dolomitic sandstones in the Conococheague Group (Wilson, 1950, Pl. 3) and probably those in the Beekmantown Group thicken westward and were derived from a lowland source to the west.

The interbedded seams of limestone and silty dolostone typical of the Conococheague (Sando, 1957, p. 35) and possibly the "tiger-striped" beds in the Saint Paul Limestone are postulated to represent growth and partial desiccation of algal mats covering lime-mud on tidal flats; the silty dolomitic bands represent dolomitized algal mats.

Beds of algal limestone (stromatolites) are common in the Rockdale Run Formation, the Conococheague Group and the Saint Paul Group and indicate shallow, clear, probably warm water.

Lime-sandstone (calcarenite) beds are present in most of the formations and indicate fragmentation and movement by traction possibly caused by shoaling of the water.

Oolite beds in the Conococheague Group indicate vigorous current action in shallow carbonate-saturated water (Hatch, Rastall, and Black, 1938, p. 178).

Edgewise limestone conglomerates, common in the Conococheague Group and lower part of the Beekmantown Group, probably represent desiccation polygons or eroded cohesive flaps of water-rich lime-mud stacked up by rather gentle currents.

Pure lime-mudstone, common in the Saint Paul Limestone and present in the Rockdale Run Formation, may be a chemical precipitate, the precipitation possibly aided by algal activity.

Dolomitic mottling of limestones, common in the Conococheague Group, Beekmantown Group, and Saint Paul Group, was determined by Sando (1957, p. 42), to be the result of dolomitization spreading outward from local centers and commonly following organic structures; this probably occurred during early diagenesis.

The mottled Beekmantown dolostones are "clearly the final product in the dolomitization process that caused the mottling of the limestones" (Sando, 1957, p. 40).

Probably the laminated Bellefonte dolostone was deposited originally as dolomite or was altered at the surface of deposition to dolomite (Sando, 1957, p. 41).

The Chambersburg and Salona argillaceous limestones indicate increased influx of terrigenous mud relative to the deposition of carbonate material. This mud appears to be the distal end of the Blountian clastic wedge, which thickens and coarsens to the southeast. The irregular bedding typical of the Chambersburg Limestone might be current rippling. The planar bedding and lack of disturbance of the limestone, shale and altered volcanic ash beds of the Salona Formation suggest deposition in a more stagnant environment, similar to that of the overlying Antes member of the Reedsville Formation.

ORDOVICIAN FLYSCH

Reedsville Formation

Name—The Reedsville Formation was named by Ulrich (1911, Pl. 27) for a sequence of shales with minor sandstones near Reedsville, Mifflin County, 50 miles north-northeast of the quadrangle. Rocks within the McConnellsburg quadrangle are designated as Reedsville Formation rather than Martinsburg Formation in conformity with the areal boundaries drawn by McBride (1960) and shown on the Geologic Map of Pennsylvania (Gray and others, 1960).

Outcrop belts and thickness—Near the mountains the Reedsville Formation underlies the lower part of the anti-dip slopes* of the prominent ridges. It underlies slopes flanking McConnellsburg Cove and the entire Path Valley lowland near Richmond Furnace; north and south of Richmond Furnace its outcrop trace divides into two separate belts. Away from the mountains in the lowland of the Mercersburg reentrant, two outcrop belts of the Reedsville Formation form low rounded hills a hundred feet above the surrounding limestone terrain. The Reedsville Formation rarely crops out, for it weathers readily to clayey loam of the Berks soils (Higbee and others, 1938, p. 31-35). Weathered chips of shale are present in the soil of cultivated lands or between the roots of overturned trees in wooded areas. Near the mountains the bedrock, or weathered material directly derived from it, is normally covered by a foot or so of debris from the sandstones upslope.

On the southwest flank of Jordans Knob the Reedsville Formation is estimated to be 2,500 feet thick. Just east of McConnellsburg it measures 1,950 feet in thickness, yet for 2 to 5 miles north of there it measures only 1,000 feet. This thinned section of the Reedsville Formation is located where the middle Ordovician limestones measure less than one-quarter their normal thickness. The thinning lines up remarkably well with the Adirondack axis of Kay (1951, p. 57). Nevertheless, estimates of the thickness of the incompetent Reedsville Formation are possibly subject to large errors as a result of poor exposures and complex deformation.

Character—The Reedsville Formation can be divided into three members: a basal black shale member, a member consisting of shale with minor beds of siltstone and sandstone, and an upper member consisting of shale cut by channels filled with coarse-grained fossiliferous sandstone. These members were not mapped separately because of their gradational nature, poor exposures, and common cover by sandstone debris.

The lowermost member is at least 50 feet and possibly several hundred feet thick and consists of graptolitic black shale. In central Pennsylvania it was named the Antes Formation (Kay, 1944, p. 114), but in this report it is considered a member of the Reedsville Formation. Where fresh, the shale is dull black; where weathered, it is clayey brown. It is composed of about 40 percent quartz silt, 45 percent clay of the illite type, 5 percent mica flakes, and perhaps 10 percent carbonaceous matter, largely graptolites. Laminations of lighter colored silty shale about 0.1 inch apart define the stratification. The shale is highly fissile and weathers into slabs about a quarter of an inch thick. This member is generally not calcareous.

The middle member, about 1,000 feet thick, consists of shale with thin beds of siltstone or fine-grained sandstone. Fresh shale is dark gray to

* See p. 61 for definition.

olive gray; weathered shale is brown to yellowish orange. Although some of the shale is calcareous, most of it is not. The siltstone and sandstone beds are normally 1 to 4 inches thick and together compose about 25 percent of the total thickness of the member; siltstone is about four times more common than sandstone. The siltstone beds are horizontally laminated and ripple cross-laminated and may show crude grading. Bottom marks were not observed. Along the west side of Kittatinny Mountain, a concentration of calcareous sandstone beds 4 to 6 inches thick occurs in the middle of the member. These sandstone beds form a prominent bench on the mountainside.

The upper member consists of dark-gray to olive-gray shale containing lenticular beds of fossiliferous sandstone. The sandstone is a coarse- to fine-grained lithic wacke.* It is medium gray and calcareous where fresh, but normally it is seen as weathered fragments of yellowish-brown, friable sandstone containing cavities partly filled by iron oxide; these cavities are formed by solution of fossils. The sandstone beds are graded and fill channels 6 inches to 5 feet deep in the underlying shale. This sequence of interbedded shale and sandstone is described later with the measured section of the Bald Eagle Sandstone where within an interval of several hundred feet the sandstone increases from 20 to 90 percent of the section.

Two large masses or pods of dark-gray argillaceous limestone were noted in the Reedsville shale. One is shown in the southwest corner of the quadrangle, and the other crops out nearby above a western meander of West Branch, 800 feet south of the quadrangle. The two masses occur at about the same stratigraphic position, but appear to be lenticular or even block-like rather than part of a continuous bed.

The upper contact is gradational, and is drawn arbitrarily at the base of the lowest massive sandstone bed that is not overlain by a sequence 20 feet thick with more than 10 percent gray shale. This contact is mapped on the basis of the highest significant shale float and a slight increase in slope at the base of the Bald Eagle Sandstone. This increase in slope is not as pronounced as that between the middle and upper member of the Reedsville Formation or between the lower and upper part of the Juniata Sandstone.

Age—The lowest part of the Reedsville Formation is of Trenton age. Graptolites from the black shale member in McConnellsburg Cove were identified by W. B. N. Berry (written communication, 1963) as probably from the *Orthograptus truncatus*, var. *intermedius* Zone. They are:

* C. M. Gilbert's classification of sandstones is used in this report (Williams, Turner, and Gilbert, 1958, p. 292-3.)

Locality AHF-1F-55-1. Approximately 5 feet above the Tuscarora fault and base of the black shale member. (Antes Formation)

Corynoides calicularis Nicholson

Corynoides comma Ruedemann?

Orthograptus cf. *O. quadrimucronatus* (Hall)

Orthograptus calcaratus n. var.?

Orthograptus n. sp.

Locality AHF-1F-57-1. Approximately 25 feet above the base of the black shale member (Antes Formation). Groups A and B are separated in outcrop by a fault of undetermined displacement.

Group A

Climacograptus sp.

Corynoides calicularis Nicholson

Diplograptus multident Elles and Wood

Orthograptus calcaratus cf. var. *acutus* (Lapworth)

Orthograptus truncatus cf. var. *pertenuis* (Ruedemann)

Orthograptus n. sp. (like that in collection 55-1)

Orthograptus sp.

Group B

Climacograptus sp.

Diplograptus multident Elles and Wood

Orthograptus cf. *O. quadrimucronatus* (Hall)

Orthograptus sp.

Probably the black shale member correlates with the Coburn Limestone and lower part of the Antes Formation in central Pennsylvania, and with the middle of the Martinsburg Formation in the Great Valley.

Fossils from the upper member were collected from the locality given in the measured section of the Bald Eagle Sandstone, and may be studied at a later date. These fossils are presumably of Maysville age.

According to McBride (1960) the Reedsville Formation is equivalent to and younger than the upper part of the Martinsburg Formation in the Great Valley.

Origin of the Reedsville Formation

The Reedsville Formation contains sand, silt, and clay derived from an eastern source that was raised above the sea during an early part of the Taconic Orogeny. The sedimentary sequence from the Chambersburg Salona Formations, through the three members of the Reedsville Formation, and to the sandstones of the Taconic clastic wedge, displays a progressive increase in grain size and probably indicates a westward migration of the locus of sediment deposition.

The black shale member at the base of the Reedsville Formation was deposited in a reducing environment in which the rate of introduction of organic matter exceeded that of its destruction. Quartz silt, clay, and organic matter were slowly deposited in a low-energy environment. The

fine laminations, the concentrations of graptolites on some bedding planes, and the high organic content suggest that the black shale was deposited in stagnant, poisonous, bottom water and that the water may have repeatedly overturned. The water may have been a few hundred to a few thousand feet deep. The black shale was deposited in water deeper than the contemporaneous shallow-water limestone a few tens of miles to the west (Thompson, 1963, Fig. 15). It could not have been much if any deeper than the trough of Martinsburg deposition to the east, into which west-flowing turbidity currents were deflected and in which turbidites were being deposited (McBride, 1962).

The middle member represents quiet deposition of mud sporadically interrupted by introduction of silt and sand in turbidity currents, storm waves, or slumps. Absence of distinctive bottom marks and the predominance of silt over sand suggest that the velocity of turbidity currents was rather low. The currents may have previously had velocities capable of erosion and transport of sand; this phase of the currents may be represented by coarser beds of the upper Martinsburg Formation to the east.

The upper member was deposited under conditions of stronger currents, presumably on steeper slopes nearer the eastern margin of the basin of deposition. Currents cut channels a few feet deep in the mud bottom and filled these channels with coarse to fine sand. This could have been in the region just below the source area of the turbidity currents or slumps. More and more sand was deposited relative to mud, until, during Bald Eagle deposition, sand deposition was predominant in this area. Perhaps this transition represents the change from a zone of slumping below a marine scarp to a zone of shallow-water marine accumulation shoreward from the scarp.

The source of the sand grains of the middle and upper members was a highland to the east underlain primarily by Cambrian quartzites, Cambrian and Ordovician carbonate rocks, and the older parts of the Martinsburg Formation (after McBride, 1962, p. 87).

SANDSTONES OF THE TACONIC CLASTIC WEDGE

A natural lithologic and genetic group is formed by the Bald Eagle, Juniata and Tuscarora Sandstones. These rocks, which make up the core of the Taconic clastic wedge, range in age from Late Ordovician to probably Early Silurian. In the McConnellsburg quadrangle their aggregate thickness is 1,200 feet. They form all the higher ridges. The Tuscarora Sandstone underlies the ridge crests; the Juniata and Bald Eagle Sandstones underlie respectively lower positions on the anti-dip slopes* of the ridges. The sandstones weather to form "DeKalb or Lehigh soil material" (Higbee and others, 1938, p. 62).

* See page 61 for definition.

Bald Eagle Formation

Name—The Bald Eagle Formation (Oswego of earlier reports) was named by Grabau (1909, p. 235) for exposures of greenish sandstone that form a prominent bench on the side of Bald Eagle Mountain near Tryone, 50 miles north-northwest of the quadrangle.

Outcrop belts and thickness—In the McConnellsburg quadrangle the Bald Eagle Sandstone underlies lower parts of the anti-dip slopes of the major ridges, but it does not form a topographic bench as at the type locality. The Bald Eagle Sandstone occurs in four outcrop belts (Pl. 1), all of which are covered by rubble of the more resistant Juniata and Tuscarora Sandstones. In fact, in some places known to be underlain by the Bald Eagle Sandstone, none of it is identifiable in a traverse across the natural surface float. At the locality of the measured section, the Bald Eagle Sandstone is 160 feet thick. Elsewhere in the quadrangle the widths of the outcrop belts indicate thicknesses between 150 and 250 feet.

Character—The Bald Eagle consists of fine- to coarse-grained sandstone, and ranges from lithic wacke to quartz arenite. Most of it is medium-grained lithic arenite cemented by 5 to 10 percent clay and iron oxide. Twenty-five to 50 percent of the sand grains consist of rock fragments composed of low-grade metamorphic rocks such as slate, phyllite, argillite, and schist (Krynine and Tuttle, 1941). Feldspar grains are rare or absent. Fresh sandstone is light olive gray to medium gray, but almost all exposures within 10 feet of the natural surface are weathered dark yellowish orange to yellowish gray. Weathering of contained siderite grains forms iron oxide stains 0.05 to 0.5 inches in diameter (Yeakel, 1962, p. 1524). These stains range in color from moderate brown to dark yellowish orange; they are here called rusty spots. Fresh Bald Eagle Sandstone is a well-indurated rock; but it readily weathers to friable argillaceous sandstone. Faint cross-stratifications dip at an angle to bedding of 1 to 20 degrees. Although some quartz grains are well rounded, most are subangular. Beds of quartz pebbles near the middle of the formation are probably related to the Lost Run conglomerate that occurs in the middle of the Bald Eagle Sandstone 60 miles northeast (Conlin and Hoskins, 1962, p. 6).

The gradational upper contact of Bald Eagle with Juniata Sandstone is drawn at the top of the highest olive-gray sandstone. As recorded in the measured section, several reddish-gray sandstone beds are included in the upper Bald Eagle Sandstone. A marked break in slope caused by changes within the Juniata Sandstone trends parallel to the contact between the Bald Eagle and Juniata Sandstones, and once this break in slope is related to the contact, it can be used to estimate the location of the contact.

In addition to the Bald Eagle exposure described in the measured section given below, the upper part of the Bald Eagle Sandstone is well exposed northeast of Cowan Gap on the dirt road that runs along the east side of Tuscarora Mountain from the gap.

Measured section—The Bald Eagle Sandstone and the adjacent parts of the underlying Reedsville Formation and the overlying Juniata Sandstone are well exposed along State Highway 16 on the west side of Tuscarora Mountain. The top of the measured section is 2.8 miles by road southeast of McConnellsburg, or 9,050 feet north of lat. 39°52'30" and 9,100 feet east of long. 78°00'. The base of the section lies across the road from the McConnellsburg town dump. The section is exposed in discontinuous road cuts along the mountain side, where 83 percent of the Bald Eagle Sandstone is exposed in one part or another of the high road cuts. The strike of the rocks is nearly parallel to the road, and consequently the section covers half a mile of exposures along the road. All the sandstones are partially weathered, even where exposed in road cuts 30 feet deep.

Top of section	Unit Thick- ness	Cumulative Thickness
Juniata Sandstone		
1. Interbedded medium- to coarse-grained lithic arenite and fine-grained shaly-weathering lithic wacke, both dusky-red to grayish-red. Some red clay pebbles and rusty spots.	13	13
2. Lithic arenite, medium- to coarse-grained, grayish-red, thick-bedded, cross-laminated. Common shale pebbles and rusty spots. (UTCo pole #52 is in middle of unit.)	21	34
3. Lithic wacke, fine- to medium-grained, dusky-red, shaly-weathering.	0.5	34.5
4. Same as unit #2, with cut-and-fill stratification. Some cross-strata are overturned with respect to bedding. Note: there is minor faulting here. (Base of unit 20 feet south of UTCo pole #51 and highway culvert.)	8.5	43
5. Lithic arenite, coarse-grained, grayish-red, cross-laminated. Rusty spots.	10	
Total Juniata Sandstone		53
Bald Eagle Sandstone		
1. Lithic arenite, medium-grained, weathers light-olive-gray, thick bedded. Rusty spots. Typical Bald Eagle lithology, although except for color the rock is almost identical with the lower Juniata Sandstone. Minor faulting. (Section measured from base of UTCo pole #50.)	3	3
2. Lithic arenite, grayish-red. Rusty spots. Typical Juniata lithology, but occurs below the highest Bald Eagle type bed.	12	15
3. Interbedded thin beds of grayish-red and olive-gray, medium-grained sandstone, both with rusty spots.	5	20
4. Sandstone, conglomeratic with quartz pebbles, grayish-red, thick-bedded. Rusty spots; clay pebbles.	7.5	27.5
5. Lithic wacke, fine-grained, grayish-red, shaly-weathering.	3.5	31

Top of section	Unit Thick- ness	Cumulative Thickness
6. Lithic arenite, medium-grained, brownish-gray.	3	34
7. Lithic arenite, coarse-grained with some quartz pebbles, dusky-yellow, thick-bedded. Rusty spots.	15	49
8. Covered interval. Float of typical olive-gray Bald Eagle Sandstone. (Resume section 420 feet down road.)	25	74
9. Interbedded dusky-yellow, medium-grained lithic arenite and moderate-yellow, shaly-weathering, fine-grained, lithic wacke. Minor fault at base of section.	10	84
10. Lithic arenite, fine-grained, dusky-yellow beds 4 feet thick, with rusty spots. Gray shale beds 0.1 to 1 foot thick compose approximately 5 percent of this section. This unit is included in the Bald Eagle Sandstone because the shale is very minor and typical Bald Eagle Sandstone underlies it.	31.5	115.5
11. Lithic arenite, fine- to medium-grained, light-olive-gray. A massive bed.	5.5	121
12. Lithic arenite, medium-grained, light-olive-gray. Contains fossiliferous <i>Orthorhynchula</i> zone.	3	124
13. Same as bed #1.	10.5	134.5
14. Lithic arenite, fine-grained, light-olive-gray. Poorly defined rusty spots. Fossiliferous with rusty imprints.	8.5	143
15. Lithic arenite, fine- to medium-grained, light-olive-gray with close-spaced rusty spots Fossiliferous with rusty imprints. Base at pole #46.	16	
Total Bald Eagle Sandstone		159
<hr/>		
Reedsville Formation		
1. Covered interval, thickness estimated.	30	30
2. Partly covered, interbedded olive-gray shale and fine- to medium-grained sandstone. Sandstone:shale ranges from 1:4 at base to 1:2 at top. Fresh sandstone is olive-gray and calcareous; weathered sandstone is orange-brown, punky, and friable. Bases of sandstone beds fill channels in shale. Sandstone beds fossiliferous. Base at UTCO pole #44.	70	100
3. Covered interval.	65	165
4. Interbedded shale and sandstone, ratio 5:1. Shale, olive-gray, dense, noncalcareous. Sandstone, fine- to coarse-grained, olive-gray, and fossiliferous. Sandstone beds are graded and thicken where they fill channels in the underlying shale. More shale down the road.	75+	
Total Reedsville Formation		240+

Age—The *Orthorhynchula* Zone, which occurs near the base of the Bald Eagle Sandstone, is considered to be of Maysville age. Presumably, the remainder of the overlying Bald Eagle Sandstone was deposited well within Late Ordovician time.

Juniata Formation

Name—The red-bed sequence between the Bald Eagle Sandstone and the Tuscarora Sandstone was named Juniata Sandstone by Darton and Taft (1896, p. 2), presumably from exposures along the Juniata River in central Pennsylvania.

Outcrop belts and thickness—Juniata Sandstone has four belts of outcrop (Pl. 1). It occurs high on the anti-dip slope of the prominent ridges, where it underlies slopes covered with rubble of Tuscarora and Juniata Sandstone. Measurement of thickness based on width of the outcrop belt range between 425 and 700 feet; no systematic variation in thickness is apparent across the quadrangle.

Character—The Juniata Sandstone consists of thick beds of fine- to coarse-grained sandstone, ranging from lithic wacke to quartz arenite. The rock is generally some shade of grayish red, but ranges from dark-reddish-brown, impure sandstone to pink quartz arenite. Angular to sub-rounded grains are cemented together by clay, hematite, and silica. Rock fragments in the lower part of the sandstone are similar in composition to those in the Bald Eagle Sandstone (Krynine and Tuttle, 1941). In a general way the Juniata Sandstone represents a lithologic transition from the Bald Eagle to the Tuscarora Sandstone, grading from hematitic, poorly cemented lithic wacke near the base to silica-cemented quartz arenite at the top. Other changes occur within the Juniata Sandstone: cross-stratification changes from mixed cut-and-fill and planar near the base to planar near the top; clay pebbles and rusty spots, common near the base, disappear towards the top. In comparison with the shaly Juniata Formation noted in numerous other places in the central Appalachians, no shale was observed in the Juniata in the McConnellsburg quadrangle, although the weathered surface of some fine-grained beds of lithic wacke might easily be mistaken for shale.

The upper contact with the Tuscarora Sandstone is well exposed in numerous places. The contact is drawn at the change from some shade of red to light gray. In the uppermost Juniata Sandstone and the lowermost Tuscarora Sandstone, the resistance of the rocks, the bedding and cross-stratification, the siliceous cement, and the composition of the grains seem identical. The upper contact is mapped on a basis of the highest abundant red-sandstone float. Locally, some red beds occur a few tens of feet above the base of the Tuscarora Sandstone. These red beds are included in the Tuscarora Sandstone because more than 90 per cent of the sequence within 20 feet of these red beds is typical Tuscarora Sandstone.

Best exposures—The lower 50 feet of Juniata Sandstone is exposed along State Highway 16, three miles by road southeast of McConnellsburg; this sequence is described in the upper part of the measured section of

Bald Eagle Sandstone. The middle part of Juniata Sandstone is exposed along U. S. Highway 30, 2½ miles by road east of McConnellsburg. The contact between Juniata and Tuscarora Sandstones is exposed along the secondary road on the south side of Cove Gap, one-half mile south of the McConnellsburg quadrangle.

Age—Aside from fucoidal sole markings, no fossils have been found in the Juniata Sandstone. By convention, it is considered to be of Late Ordovician age. There are 700 feet of nonfossiliferous sandstones between the *Orthorhynchula* Zone near the base of the Bald Eagle Sandstone and the top of the Juniata Sandstone. Apparently two (?) and a half stages (Twenhofel and others, 1954) remain in the Ordovician above the *Orthorhynchula* Zone; the remainder of the Bald Eagle Sandstone and the Juniata Sandstone could have been deposited in this time.

Tuscarora Formation

Name—The light-gray or white sandstone that underlies the crests of most of the higher ridges in the Valley and Ridge province was named Tuscarora Sandstone by Darton and Taft (1896, p. 2), presumably for exposures along Tuscarora Mountain in central and southern Pennsylvania.

Outcrop belts and thickness—The Tuscarora Formation is the ridge-maker in the McConnellsburg quadrangle and, from east to west, upholds the crests of Little Mountain, Kittatinny Mountain, Hogback Mountain, Cove Mountain, Tuscarora Mountain, and Little Scrub Ridge. Rubble of Tuscarora sandstone generally covers the Tuscarora outcrop belts, but outcrops of Tuscarora sandstone are seen in many places along the ridge crests and in the gaps. Measurements of Tuscarora thickness based upon width of outcrop range from 520 to 600 feet, increasing from the southern to the northern boundary of the quadrangle. At Cove Gap the Tuscarora measures 450 feet in thickness, but may be thinned tectonically.

Character—The Tuscarora Sandstone is fine- to coarse-grained, very well-sorted quartz arenite. Fresh sandstone is medium gray to very light gray, and is usually described as white. Locally some beds of red sandstone occur in the lower part. Where weathered in normal outcrop, the rock surface is stained light brown. The quartz grains are well cemented with 5 to 20 percent silica (Wood and Griffiths, 1963, Fig. 2). Most of the beds range in thickness between 4 inches and 3 feet, and are visibly cross-stratified. The cross-stratifications are sub-planar and dip as much as 30° to the bedding. Some parts of the Tuscarora Sandstone are conglomeratic, especially in the lower two-thirds, where layers rich in pebbles of chert and vein quartz are common. Light-green shale pebbles are scattered throughout the sandstone. A few gray shale beds less than one foot thick occur in the upper part where they make up much less than 10 per-

cent of the formation. In general, the Tuscarora grades from medium- to coarse-grained, thick-bedded sandstone at the base to fine- to medium-grained, thin-bedded sandstone at the top. As noted by Folk (1959, Fig. 3), most grains in the lower part are angular, whereas grains in the upper part are well-rounded.

The upper contact with the Rose Hill Formation is gradational through a few tens of feet. As the contact is approached, gray shale beds become more common and the sandstone beds finer grained and thinner bedded. The lowermost Rose Hill is gray quartzose siltstone. The upper contact of the Tuscarora Sandstone is mapped at the marked break in slope that reflects this change in rock type.

Age—Although *Arthropycus*- and *Scolithus*-like tubes occur in the Tuscarora Sandstone, no fossils adequate for dating have been found. Present practice places the Silurian-Ordovician boundary between the Juniata and Tuscarora Sandstones, yet all that is known is that the Silurian-Ordovician boundary occurs somewhere between the lower part of the Bald Eagle Sandstone and the Rose Hill Formation. It is improbable that the Silurian-Ordovician boundary does, in fact, occur at the contact between the Tuscarora and Juniata Sandstones, for this contact is gradational with no evidence of a time break and is no more likely a period boundary than any other bedding plane.

Origin of the Sandstones of the Taconic Clastic Wedge

The Bald Eagle, Juniata, and Tuscarora Sandstones form a wedge-shaped body that thickens and coarsens eastward, and as these sandstones are associated in time and place with the Taconic Orogeny, they are referred to as the Taconic clastic wedge. In the central Appalachians, the dip of the cross-stratifications, and thickness and grain-size changes indicate that these sandstones were deposited by currents flowing to the west from a landmass to the east. The gross current pattern shows one dispersal center south of the McConnellsburg quadrangle in northern Virginia, and another northeast, in eastern Pennsylvania (Yeakel, 1962, Figs. 11, 13 and 17). Hypotheses on the environments of deposition for these sandstones range from shallow-water marine to alluvial plain. Yeakel (1962, p. 1534) concluded that the Bald Eagle, Juniata, and Tuscarora Sandstones are alluvial sediments. Folk (1960, p. 21), concluded that the Tuscarora Sandstone was a beach sediment whereas the Juniata Sandstone was an alluvial sediment.

The sandstones of the Taconic clastic wedge form part of a continuously gradational sequence from the Reedsville Formation to the Rose Hill Formation. During deposition of the upper member of the Reedsville Formation, it is postulated that the water was becoming shallower and the shoreline nearer, as discussed previously under "Origin of the Reedsville Formation."

The lower part of the Bald Eagle Sandstone contains the marine *Orthorhynchula* Zone. Since the rest of the Bald Eagle Sandstone is very similar to the sediments near the *Orthorhynchula* Zone, it is reasonable to suppose that most or all of the Bald Eagle Sandstone is a shallow-water marine deposit. Olive-gray color and siderite grains indicate that the Bald Eagle was deposited in a slightly reducing environment. Clasts of sand and gravel mixed with silt and clay suggest that strong currents brought all this detritus to the site of deposition, but that subsequent winnowing was not very intense.

The obvious difference between Juniata and Bald Eagle Sandstone is a change in color from green to red. This reflects a change in the environment of deposition from slightly reducing to oxidizing. Rusty spots in the lower Juniata indicate siderite was formed, either at the site of deposition or near it. The presence of siderite and hematite suggests Eh-pH conditions near the siderite-hematite equilibrium boundary (Garrels, 1960, Fig. 6.23). Cut-and-fill stratification and red-clay pebbles in the lower part of the Juniata Sandstone indicate local deposition and erosion and suggest alluvial deposition. Well-sorted Juniata Sandstone, denoting a high-energy environment, probably was deposited in stream channels; poorly sorted Juniata Sandstone (and shale noted outside the McConnellsburg quadrangle), denoting a lower-energy environment, probably was deposited on flood plains.

The transition from Juniata to Tuscarora Sandstone is also gradational. The Tuscarora is a well-washed, mature sandstone, and must have been deposited in a high-energy environment. Researchers have suggested alluvial plain, beach, offshore bar, and shallow-water-marine environments of deposition, but none of the suggested environments of deposition appear to explain adequately this sheet of quartz sand. The thickness of the Tuscarora Sandstone is much greater than any well-established beach sediment. Beach sediments display cross-stratifications that dip less than 10° , whereas those in the Tuscarora Sandstone dip as much as 30° . If the Tuscarora Sandstone is a nearshore marine sediment, why is there no evidence of marine fossils? Were the fossils leached during diagenesis? If the Tuscarora is an alluvial plain sediment, it is remarkable that no significant flood-plain sediments are found interbedded with it, and that thousands of square miles of country could be completely covered at one time or another by several hundred feet of uninterrupted stream channel sediments. The low degree of rounding of the lower Tuscarora Sandstone indicates a rapid supply and limits the time of exposure in a high-energy environment, whereas the high degree of rounding of the upper Tuscarora Sandstone suggests that the grains there were subject for a considerable time to a high-energy environment, such as the wave zone. Marine incursion had occurred by the time the Rose Hill was deposited.

Petrographic studies by Krynine and Tuttle (1941) and Folk (1960) show that the source area for the sandstones of the Taconic clastic wedge consisted of: (1) quartz-bearing sedimentary rocks (sandstone, quartzite, and carbonate rocks), (2) low-grade metamorphic rocks (mostly slate), (3) vein quartz (from hydrothermal deposits) and chert (from carbonate rocks) especially during deposition of Bald Eagle and Juniata Sandstones and (4) granitic plutonic rocks, especially during deposition of the upper Tuscarora Sandstone. No sand from volcanic rocks occurs in these sandstones, suggesting either that volcanic material, if present, was completely altered by weathering in the source area, or that the source was not a volcanic island arc, but a highland of sedimentary, low-grade metamorphic, and granitic rocks.

SILURIAN SHALES AND ASSOCIATED SEDIMENTS

A thickness of about 1,200 feet of Silurian sedimentary rocks overlying the Tuscarora Sandstone is exposed in the quadrangle. These rocks are mostly shale with some beds of sandstone and limestone and are divided into the Rose Hill Formation and the Mifflintown-Bloomsburg Formation.

Rose Hill Formation

Name—The Rose Hill Formation was named by C. K. Swartz (1923, p. 27-28) for exposures on Rose Hill, near Cumberland, Maryland, 40 miles west-southwest of McConnellsburg.

Outcrop belts and thickness—The Rose Hill Shale underlies gentle slopes on the floor of Allen Valley, narrow rolling uplands around Jordans Knob and near Bear Lick on Cove Mountain, and steep slopes on the west flank of Cove Mountain south of Buchanan Summit. Except for the Centre Sandstone Member, the formation rarely crops out; usually its outcrop trace is mantled with residuum or debris from sandstone upslope. The Rose Hill is about 650 feet thick.

Character—The Rose Hill Formation consists of clayey to silty shale with subordinate beds of sandstone and siltstone. Most of the shale is olive gray or gray. The upper half of the formation contains some beds of moderate-pink (rose) and very-dusky-red-purple shale. The shale weathers to light brown, yellow, or pink. Mica flakes on weathered bedding surfaces of the shale, especially in the upper part of the formation, give plates of shale a characteristic sheen. The beds of sandstone are fine grained and generally a few inches thick. The lower part of this formation contains some resistant beds of bluish-gray quartz arenite with a silica cement, but most of the sandstone beds are calcareous and weather readily to a punky brown sandstone. Many sandstone beds are ripple cross-laminated, graded, and have flute casts on the bottoms. In places, pods of sandstone an inch or so in diameter are imbedded in the shale.

The Centre Sandstone Member (Miller, 1961, p. 9 and Swartz and Swartz, 1931, p. 629) is characterized by resistant beds of dusky-red, hematitic, or "iron," sandstone, and is 35 feet thick. It occurs 150 to 200 feet below the top of the Rose Hill Formation, and consists of quartz sandstone that is well cemented and selectively replaced by hematite. The rock is quite resistant and well indurated, and breaks with a conchoidal fracture. The member contains two five-foot-thick beds of cross-laminated, medium- to coarse-grained, "iron" sandstone, one at the base and one near the top. The remaining 25 feet consists of beds of "iron" sandstone 0.1 to 2 feet thick, separated by thinner beds and pairings of lustrous red and yellow shale.

A lower "iron" sandstone zone is moderately well developed in Horse Valley about 500 feet below the top of the Rose Hill Shale, and is probably the Cabin Hill Member of Miller (1961, p. 10-11), named for exposures 30 miles northeast along strike.

Isolated thin beds of "iron" sandstone occur in the upper two thirds of the Rose Hill Shale, and are similar to sandstones of the Centre Member.

The upper contact of the Rose Hill Shale with the Keefer Sandstone Member of the Mifflintown Formation is gradational through a few feet and is drawn at the base of the first light-brown or gray quartz arenite bed. This contact is readily mapped, for this change in rock type is accompanied by a well-defined change in slope.

Best exposures—About half a mile south of the quadrangle, the lower part of the Rose Hill Shale up to the Centre Member is exposed continuously for 0.4 mile east along State Highway 16 from the intersection of State Highways 16 and 456. On U. S. Highway 30, in the vicinity of Buchanan Summit, much of the Rose Hill Shale is exposed in road cuts and quarries, including an old quarry in the Centre Sandstone Member just east of Buchanan Summit.

Age—The Rose Hill Formation contains an abundant fauna and is placed by Swartz (1942) in the early part of Niagaran time (middle Silurian).

Mifflintown and Bloomsburg Formations

Name—As the Mifflintown and Bloomsburg Formations underlie only a small portion of the quadrangle and rarely crop out, they are here combined for mapping purposes and are identified as the Mifflintown-Bloomsburg Formations undivided. The Mifflintown Formation was re-defined by Miller (1961, p. 12) to include the Keefer, Rochester, and McKenzie Members, from exposures near Mifflintown on the Juniata River 55 miles northeast of the McConnellsburg quadrangle. Overlying the Mifflintown Formation are red beds commonly assigned to the Bloomsburg Formation, a unit named by White (1883, p. 106) for ex-

posures near Bloomsburg, 105 miles northeast of McConnellsburg. In the McConnellsburg area, however, an unknown thickness of red beds having Bloomsburg lithology may actually belong to the Rabble Run Member of the Mifflintown Formation, a unit which is a tongue of red beds within the McKenzie Member.

Outcrop belts and thickness—The Mifflintown-Bloomsburg unit underlies axial areas in deeper parts of the synclines along Horse Valley, Allen Valley, and Cove Mountain near Bear Lick. Except for the basal Keefer Member, outcrops are almost nonexistent; the outcrop trace is covered normally by alluvium, sandstone debris, or residuum. Beds of the Mifflintown-Bloomsburg unit present within the quadrangle measure about 600 feet, but the entire unit is nowhere exposed within the quadrangle because upper beds have been eroded away.

Character—The Mifflintown-Bloomsburg unit contains the Keefer, Rochester, and McKenzie Members and possibly the Rabble Run Member, all belonging to the Mifflintown Formation, and contains red beds such as those found in the Bloomsburg Formation.

The Keefer Sandstone Member (Stose and Swartz, 1912, p. 5) measures 35 feet in thickness and is characterized by fine- to coarse-grained quartz arenite. Most outcropping beds are light-brown, gray, or light-green sandstone, but there are less resistant beds or thin partings of red and specular hematitic sandstone and shale, especially in the lower half of the member. The lower half is characterized by thin (2 to 6 inches) irregular beds of poorly sorted, coarse- to fine-grained sandstone with angular grains. The upper half is characterized by thick (1 to 3 feet) cross-laminated beds of well-sorted, medium- to fine-grained sandstone with rounded grains. Vertical tubes about half an inch in diameter are filled with sand. Some parts of the sandstone are quite fossiliferous, but preservation of detail is poor in the usually leached sandstone.

The McKenzie and Rochester Members are nowhere exposed but are thought to contain the dark shales and limestones typical of the units. On the east shore of Cowan Gap Lake, the combined thickness of the two units is less than 100 feet.

Red beds above the McKenzie Member are poorly exposed but are found in outcrop on the east shore of Cowan Gap Lake and probably occur in the Horse Valley and Little Cove synclines. The sequence of about 200 to 400 feet contains silty shale and clayey silty sandstone at Cowan Gap. Most of these beds are grayish red, but about 15 percent are olive drab to dusky yellow. This lithology is that of either the Bloomsburg Formation or the Rabble Run Member of the Mifflintown Formation. According to Hoskins (1961, Pl. 8), about 100 or so feet of Rabble Run red beds may be present in the McConnellsburg area, based upon information derived from adjacent areas. Rabble Run beds can

be proved to exist only if the red beds can be shown to underlie as well as overlie marine beds of the McKenzie type. In the McConnellsborg area, this cannot be done because of poor exposure.

No upper contact of the Mifflintown-Bloomsburg unit is drawn within the quadrangle.

Age—The Keefer Sandstone Member at the base of the Mifflintown Formation is of middle Niagaran (middle Silurian) age (Swartz, 1942). The Bloomsburg Formation is of late Niagaran to early Cayugan (Middle to Late Silurian) age (Hoskins, 1961, p. 106).

Origin of Silurian Shales and Associated Sediments

The Rose Hill Formation was deposited during the waning phase of sedimentation associated with the Taconic Orogeny. As indicated by abundant marine fossils, the Rose Hill is a marine deposit. Most of the time the sea floor was below wave base and mud was deposited. Flute casts on the bottoms of the sandstone beds and massive cross-laminations in "iron" sandstone beds indicate times of strong currents. Probably the beds of sandstone were introduced by floods, storm waves, or turbidity currents. The Centre "iron" Sandstone Member attests to an oxidizing environment. Petrographic study by Alling (1947, p. 991-1018) showed that hematite replaced original carbonate material during diagenesis.

The Keefer and McKenzie-Rochester sequences have been postulated by Folk (1960, p. 51) to represent respectively sand deposited near and on a barrier bar, and calcareous mud deposited in a lagoon. The two subdivisions of the Keefer Sandstone Member were considered by Folk (1960, p. 50-51) to represent first deposition underwater at the edge of sand island, and then deposition in a high-energy environment such as an offshore beach.

The Bloomsburg Formation was studied in detail by Hoskins (1961). A red-bed fauna characterized by large populations but limited numbers of ostracods indicates a brackish-water environment of deposition. Deposition of mud and sand in sheets rather than in more lenticular bodies argues against an alluvial origin. Apparently the red beds were derived from red soil produced under a tropical or subtropical climate in the source area and were deposited in an oxidizing environment. Probably, the climate in the basin of deposition was arid, for salts were being deposited then in an area now only 50 miles to the west.

UNEXPOSED SILURIAN AND DEVONIAN FORMATIONS

Sedimentary rocks that normally occupy a stratigraphic interval 2,500 feet thick between the lower Bloomsburg and Brallier Formations are not exposed in the quadrangle but should underlie the Devonian sedimentary rocks in the northwest corner of the quadrangle. These unex-

posed rocks range in age from Late Silurian to Late Devonian, and comprise the upper Bloomsburg, Wills Creek, Tonoloway, Keyser, Helderberg, Oriskany, Onondaga, Marcellus, Mahantango and Harrell Formations.

SILTY SHALES AND SANDSTONES OF THE ACADIAN CLASTIC WEDGE

The lower part of the Late Devonian Susquehanna Group (Miller and Conlin, 1961) is exposed northwest of the Little Scrub Ridge fault, which is in the northwest corner of the quadrangle. These rocks are mapped as three rock units, which correspond to two informal members of the Brallier Formation, and the overlying Catskill-Brallier transition beds.

Brallier Formation

Name—The Brallier Formation was named by Butts (1918, p. 523-524), for exposures near Everett, Pa.

Outcrop belts and thickness—In the northwest corner of the quadrangle, a single outcrop belt of the Brallier Formation is characterized by rounded discontinuous strike ridges a hundred feet high. Chips of the underlying bedrock are common in the residual soils of the Ashy, Atkins, Berks, and Calvin series. Near Little Scrub Ridge, the outcrop trace is completely mantled by debris of Tuscarora Sandstone. Assuming no complication by folding and faulting, the outcrop width of the Brallier Formation as mapped indicates a thickness of about 4,500 feet. This thickness may be excessive due to complicated structure or the inclusion of formations that underlie the Brallier Formation which are hidden beneath the cover of sandstone debris near Little Scrub Ridge. Detailed mapping along strike from the quadrangle is needed to better understand this unit.

Character—The Brallier Formation is about 75 percent silty shale and perhaps 25 percent siltstone and poorly sorted sandstone. Two conglomeratic zones ten feet thick noted by Stevenson (1882, p. 76) were not observed in the quadrangle, possibly because of poor exposures. Most beds are olive gray and weather light brown or yellowish brown.

Two informal members are distinguished and mapped on a basis of color. The lower member is characterized by shale weathering dusky yellow and a paucity of dark-reddish-brown beds. As mapped, this member measures 3,500 feet in thickness, but the lower part is completely covered by sandstone debris and the basal limit is a fault contact. The upper member, 1,000 feet thick, is characterized by more than 25 percent dark-reddish-brown (chocolate-colored) shale beds and a paucity of beds weathering dusky yellow.

The upper contact is drawn beneath the first grayish-red bed (not the first chocolate-colored bed).

Age—The Brallier Formation is fossiliferous. It correlates with the upper part of the Fort Littleton Formation of Willard (1935) which he con-

sidered to be of Chemung age (middle Late Devonian). Near the Little Scrub Ridge fault, rocks of Finger Lakes age may be present.

Catskill-Brallier Transition Beds

Name—The designation “Catskill-Fort Littleton transition beds” was applied by Miller and Conlin (1961) to the sequence of grayish-red and non-red beds between typical “marine” beds of the Fort Littleton Formation and “continental” red beds of the Catskill Formation in central Pennsylvania. The unit is now identified as Catskill-Brallier because the term Fort Littleton has been abandoned by the Pennsylvania Geological Survey in favor of the terms Harrell and Brallier (Hoskins, 1963, p. 200).

Outcrop belts and thickness—In the extreme northwest corner of the quadrangle, the lower 1,000 feet of these “transition beds” underlies rather hilly terrain with strike ridges one hundred feet high mantled by sandy residual Calvin soil (Unpublished report, Soil Conservation Service, McConnellsburg). No outcrops of these “transition beds” were observed within the quadrangle, but their character is revealed by grayish-red sandstone float and red soil.

Character—As indicated by float within the quadrangle, the Catskill Brallier transition beds consist of poorly sorted sandstones and silty shales. The color of the rock is grayish red and gray, with minor beds of dark reddish brown. The upper contact of this unit is not mapped within the quadrangle.

Age—Fossils and regional stratigraphic relations indicate that this unit is of middle Late Devonian age.

Origin of Shales and Sandstones of the Acadian Clastic Wedge

The Devonian sedimentary rocks exposed in the northwest corner of the quadrangle belong to the lower part of a section of clastic rocks about 10,000 feet thick associated in time and place with the Acadian Orogeny. They are therefore called the Acadian clastic wedge. These sediments are derived from a source area to the east composed of low-grade metamorphic and sedimentary rocks (McIver, 1961). Marine fossils indicate that the Brallier Formation was deposited in a marine environment. Beds of sand may be turbidites (McIver, 1961). The Catskill-Brallier transition beds presumably represent the transition from marine to continental conditions.

STRUCTURE

Rocks within the McConnellsburg quadrangle display a considerable variety of structures, including large folds and faults (Fig. 2). The quadrangle lies in the region of concentric, or flexural, folding a few miles west of the midprovince structural front (Rodgers, 1953, p. 151); east of

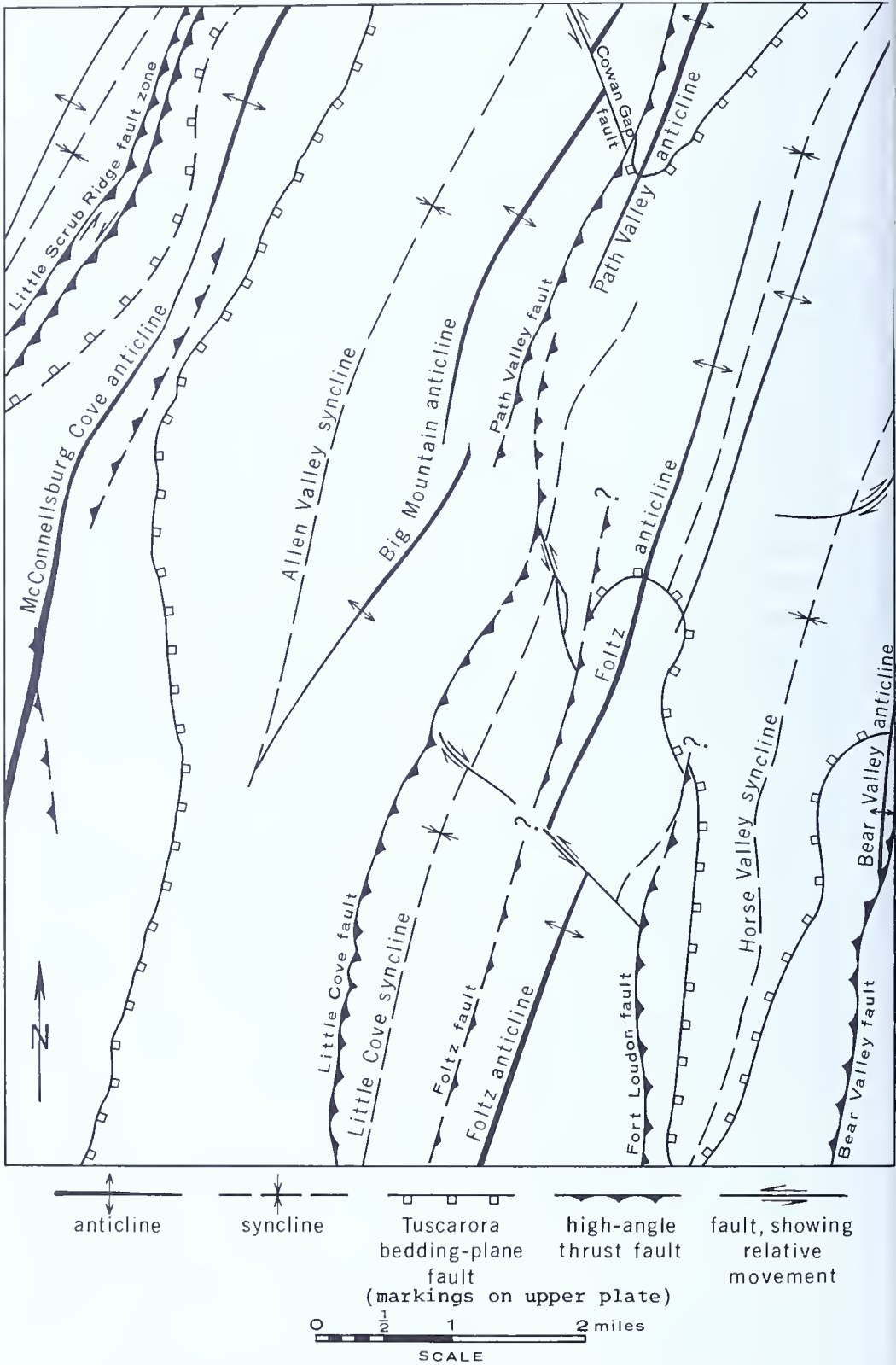


FIGURE 2. Major structures of the McConnellsburg quadrangle.

this front lie the Great Valley and South Mountain belts where similar folding becomes predominant.

The McConnellsburg Cove anticline brings up the oldest rocks exposed anywhere in the central Appalachians between the Great Valley and the Nittany arch. A diagonal culmination trending northwest across strike is formed by the McConnellsburg anticline and the various folds in the Mercersburg reentrant. This culmination stops at Little Scrub Ridge, where, west of the quadrangle, it is replaced by a major diagonal depression containing the Meadow Ground syncline and the Broad Top syncline.

The maximum structural relief is about 16,000 feet. As indicated by structures exposed at the surface, shortening of the sedimentary cover is about 27 percent.

STRUCTURAL UNITS

Rocks of the sedimentary cover in the central Appalachian Valley and Ridge province are divided into the nine rock groups shown in Figure 7. The middle part of this sedimentary cover is exposed within the McConnellsburg quadrangle; it consists of the five groups of formation discussed in the section on stratigraphy.

Carey (lecture at Yale University, 1959) and Biot (1961) have suggested that concentric folds are formed by flowage when rocks with highly contrasting viscosities are slowly deformed. At the time of deformation the sedimentary cover of the Appalachian Valley and Ridge province consisted of rocks with highly contrasting viscosities: for example, the Tuscarora sandstone was probably on the order of 100 to 1,000 times more viscous than the Reedsville shale. Biot (1961, p. 1608) estimated that in an interval of only about one million years it would be possible to produce Valley-and-Ridge-type folding primarily by flowage or viscous deformation. The traditional portrayal of the structural behavior of rocks by contrasting competent with incompetent units, which came from study of the Appalachian sedimentary cover (Willis, 1893, p. 213-281), may resolve to differences in the viscosity of the rocks.

Carbonate Rocks

Cambrian and Ordovician carbonate rocks above the Waynesboro Formation form a massive competent unit 7,000 feet thick (Fig. 7). West of the South Mountain fold these rocks were relatively cool and had a moderately high viscosity at the time of deformation. They are now bent into broad open folds.

Carbonate rocks are more commonly broken by large thrust faults than the overlying rocks. As seen in many quarries, slickensided bedding surfaces indicate slippage along bedding planes.

A study of deformed oölites by Cloos (1947, Pl. 7, Figs. 9 and 10, and Pl. 9) suggests that carbonate rocks experienced body deformation of 100 percent on the flank of South Mountain 20 miles east of the quadrangle, but less than 10 percent, if any, in McConnellsburg Cove. Changes of the "original" thickness by up to 10 percent may have resulted from body deformation of carbonate rocks within the quadrangle. Formation of stylolites may account for thinning by more than 10 percent.

Mudrock with Associated Rocks

Shale and sandstone of the Reedsville Formation and mudrock, sandstone of lower Silurian to middle Devonian formations make up two incompetent structural units. At the time of deformation these rocks had relatively low viscosities, especially those beds rich in clay or with abnormally high fluid pressures.

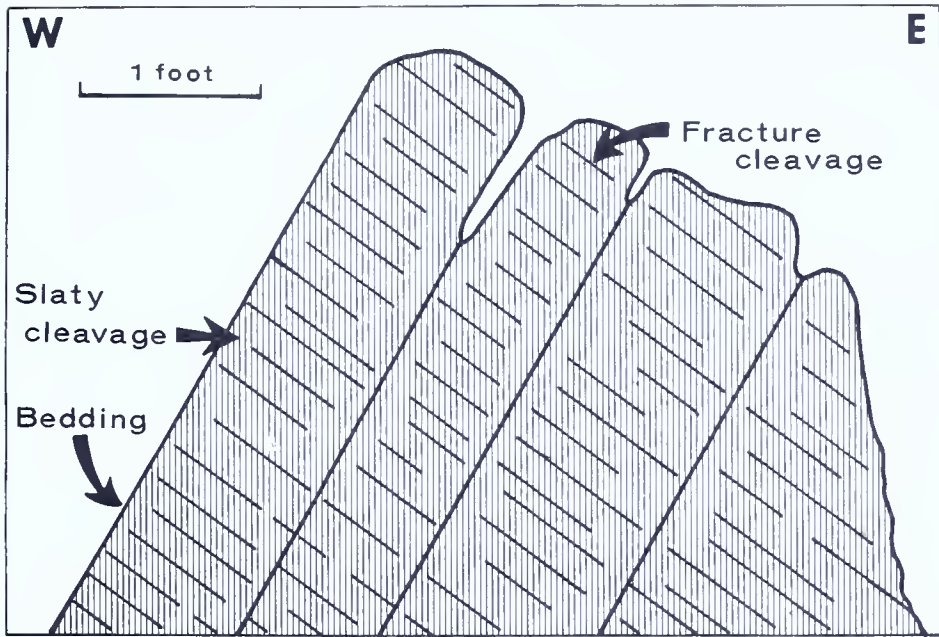
Within the quadrangle these rocks locally display disharmonic folds, such as the anticlinal crenulation in the trough of the Horse Valley and Allen Valley synclines (Pl. 1). Elsewhere within the quadrangle, disharmonic folds are not well developed, for the strikes and dips of these incompetent rocks are normally consistent with the major structures shown by the adjacent competent units. On the other hand the Upper Silurian Wills Creek Shale (unexposed in the quadrangle, is deformed into disharmonic folds where it crops out in nearby areas (Miller, 1961, Pl. 1).

Bedding-plane slips and wedges resulting from low-angle faulting were observed locally in Rose Hill shale; they are similar to those described from Maryland by Cloos (1961).

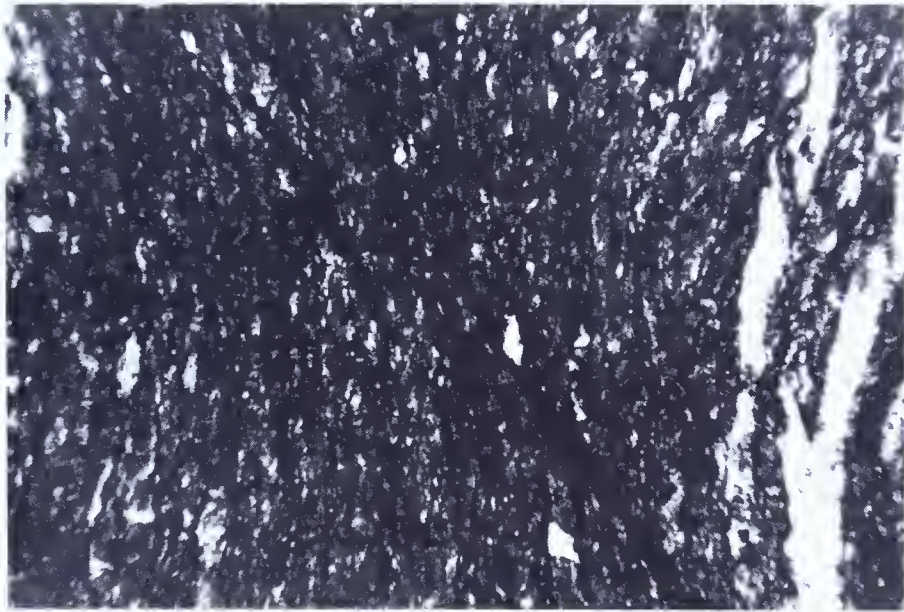
An axial-plane cleavage occurs in the Reedsville shale. From east to west across the quadrangle it tends to change from slaty cleavage to fracture cleavage. At the base of the Reedsville shale in the Mercersburg reentrant, calcareous shale displays vertical axial-plane slaty cleavage cut by east-dipping fracture cleavage (Fig. 3). Well-developed slaty cleavage defined by closely spaced seams of clay is bent or sheared into the later, more widely spaced, fracture cleavage, as shown by Figure 3. Calcareous shale generally shows better developed cleavage than nearby non-calcareous shale. For example, parts of the Salona Formation near McConnellsburg display slaty cleavage while the Reedsville shale shows fracture cleavage. The Silurian shales are cut by poorly defined fracture cleavage.

A joint set in the Reedsville shale is perpendicular to axes of the major folds, and is helpful in determining plunge of folds within this thick unit.

Crenulation, faulting at low angles to bedding, and intergranular flowage associated with formation of slaty cleavage, probably account for thickness changes of more than 15 percent in these incompetent rocks.



A. Sketch of outcrop, looking north. Note that vertical slaty cleavage is cut by east-dipping fracture cleavage.



B. Photomicrograph of some calcareous shale, looking north. Note that vertical slaty cleavage is bent or sheared into later, east-dipping fracture cleavage. Diagonal of photograph is 1 mm.

FIGURE 3. Two cleavages in calcareous shale. Outcrop of Salono Formation located along Buck Run on southern boundary of quadrangle, 200 feet upstream from Mercersburg Sportsmen's Club.

Sandstone

The Sandstones of the Taconic clastic wedge form a massive, competent, but rather thin layer, which at the time of deformation had relatively high viscosity. These rocks are bent into broad open folds, and when deformed rapidly were apparently brittle, breaking into blocks such as those along the Little Scrub Ridge fault (Pl. 1).

Most major faults in the western half of the quadrangle (except the Tuscarora fault) locally follow a bedding plane near the bottom or top of the Tuscarora Sandstone, the most competent unit in the quadrangle.

Synclinal buckling along the crest of the Big Mountain anticline, and anticlinal buckling in the trough of the Horse Valley syncline are suggested by the map pattern of the Tuscarora-Juniata contact.

Few outcrops of rocks of the Acadian clastic wedge (Upper Devonian) were observed within the quadrangle. This sequence is about 7,000 feet thick and forms a massive competent unit.

FOLDS

Approximately three major anticlines and three major synclines are encountered in any traverse across the quadrangle. The geometry of these folds, including the changes along strike, is shown in Plates 1 and 2, and Figure 2. Average wave length is about three miles; average amplitude is about one mile. The plunge of folds ranges from about 10° south to 10° north. Strike length of anticlines averages about 50 miles; the McConnellsburg anticline dies out only 15 miles north of its maximum culmination. The Foltz anticline and the Path Valley anticline have an en echelon arrangement, one increasing in amplitude as the other dies out (Pl. 2, Sections AA', BB', CC').

An interesting example of changes in structure along strike involves the Allen Valley syncline and the Big Mountain anticline (Pl. 2, Sections AA', BB', CC', DD'). As the axes of the anticline and syncline converge toward the south, the folds decrease in amplitude until they no longer exist, showing that the anticline and syncline are complementary and were formed from an initially unbent segment.

The axial planes of all the anticlinal folds with large thrust faults are inclined parallel to the dip of the faults, generally toward the east. Axial planes of most of the synclines are inclined toward the east. In places the axial planes of the Big Mountain anticline, and Allen Valley and Horse Valley synclines appear to be nearly vertical or even inclined toward the west.

Most of the folds are sharply bent along their axes and have rather planar limbs. This generalization does not hold for the broadly curved sandstone beds in the southern, less deformed segments of the Big Mountain anticline and Allen Valley syncline, which suggests that sharp bend-

ing along the axes occurred after an initial, more even, flexing of the rocks. No flat-bottomed synclines, such as the Broad Top syncline, occur in the quadrangle.

Anticlinal crenulation occurs in the shaly Silurian rocks along the axial parts of the Allen Valley syncline and possibly the Horse Valley syncline. Similar buckling also is indicated by the map pattern of the competent Tuscarora and Juniata Sandstones along the axes of the Big Mountain anticline.

Apparently east-west flexing or cross folding has helped fracture the sandstones at Cove Gap, south of the quadrangle.

FAULTS

More large faults are mapped in and near the quadrangle than in any other equivalent area in the Valley and Ridge province of Pennsylvania, Maryland, West Virginia, and northern Virginia, excepting perhaps parts of the Nittany arch. The faults within the quadrangle are divided into three groups: high-angle thrust faults, cross faults, and the Tuscarora bedding-plane fault (Pls. 1 and 2, Fig. 2).

Excepting the Tuscarora fault, none of the major fault planes were observed in the field, nor was their dip apparent from the outcrop trace, except that of the nearly vertical Cowan Gap cross fault. Drag-folds, exposed just south of the quadrangle along State Highway 16, 0.4 miles east of its intersection with State Highway 456, indicate that the Little Cove fault is an east-dipping reverse fault. All the faults are assumed to be compressional faults, but unrecognized Triassic normal faults might be present.

High-angle Thrust Faults

High-angle thrust faults are of two kinds: east-dipping and west-dipping. Dip-slip movement on these faults as shown on the cross sections (Pl. 2) is as follows: Little Scrub Ridge fault, 5,000 feet (Section AA') to 10,000 feet (Section DD'); Little Cove fault, 3,000 feet (Section CC'); Path Valley fault, 4,000 feet (Section AA'); Foltz fault, 2,500 feet (Section DD'); and Bear Valley fault, 4,000 feet (Section CC'). The east-dipping faults are postulated to flatten at depth into a decollement zone.

The Little Scrub Ridge fault has a strike length of only about 25 miles, but its dip-slip movement is a few miles at the point of maximum displacement just west of the quadrangle. Within the quadrangle this fault forms a fault zone that encompasses Little Scrub Ridge. Most movement occurred on the northwest side of the ridge where Lower Silurian rocks rest on upper Devonian rocks; just north of the quadrangle at Knobsville Gap there appears to be a sliver of Bloomsburg mudstone along this part of the fault.

Strike-slip faults in the Little Scrub Ridge fault zone are among the most interesting structural features in the quadrangle. Little Scrub Ridge is low and quite irregular as compared with the other ridges. Along the ridge crest at intervals of 1,000 feet or so are sags 50 to 300 feet deep. Most of the ridge crest is underlain by steeply dipping Tuscarora Sandstone that strikes about 35° northwest of the strike of the ridge. The Juniata and locally the Bald Eagle Sandstone approach the ridge crest in the area of the sags, and in the deeper sags actually underlie it. Strike-slip faults with right-lateral displacement of about 500 feet were observed in about half of the sags shown with faults in Plate 1, and are postulated to occur in the remaining sags, for although the Tuscarora Sandstone is only about 500 feet thick, it strikes across the ridge at a high angle. Along most of the ridge the Juniata and Bald Eagle Sandstones are greatly thinned and locally either the Tuscarora, Juniata, or Bald Eagle Sandstone is absent. Apparently shale fills in the triangular spaces between the sandstones and the thrust faults. The net effect of all these strike-slip faults is shortening perpendicular to the strike of the thrust fault zone, and elongation parallel to the strike. Shortening perpendicular to strike is compatible with other compressional structures of the Valley and Ridge province. Elongation along strike may have resulted from extension in the upper plate of the thrust, for the thrust fault is only 25 miles long, yet west of McConnellsburg it has a displacement of 3 miles.

The Path Valley fault also appears to have broken up and thinned the Tuscarora, Juniata, and Bald Eagle Sandstones near Cowan Gap. As shown on the map (Pl. 1) these sandstones are locally thinned to less than half their normal thicknesses. Much slickensiding and silicification are shown by the sandstone float.

It is remarkable that the sandstones could have been so altered by movements on the Little Scrub Ridge and Path Valley faults, and yet still present a mappable stratigraphic sequence.

The Little Cove and Path Valley thrust faults are arranged en echelon. A highly deformed zone occurs where they overlap near Hogback Mountain (Pl. 1).

West-dipping thrust faults (the Bear Valley fault and the hypothetical fault in McConnellsburg Cove) are postulated to intersect or merge with the more fundamental east-dipping faults. On Cross sections CC' and DD' (Pl. 2) the block between the east-dipping Fort Loudon thrust fault and west-dipping Bear Valley thrust fault is shown as a hemicylindrical mass completely bounded by thrust faults. This interpretation implies that the wedge-shaped mass to the east moved along the east-dipping fault and beneath the west-dipping fault.

The interpretation of the Bear Valley fault as shown in Section DD' (Pl. 2) is open to question. Identification of the Rockdale Run Formation

west of the fault is supported by the character of the rocks and their age as indicated by fragmentary fossils (as discussed previously under "stratigraphy"). But these rocks might represent the lithologically similar but younger Saint Paul Limestone on the east limb of a faulted anticline; in this case, inferred movement on the fault (Pl. 2, Section DD') would be 2,000 rather than 4,000 feet. South of the quadrangle the Bear Valley fault bounds the west side of an axially depressed zone in the crest of the Mercersburg anticline (Stose, 1909, p. 14, Fig. 4). Stose indicated that the Mercersburg anticline is a complicated structure. If it is to be fully understood, the area south of the quadrangle near Mercersburg must be mapped in greater detail.

Cross Faults

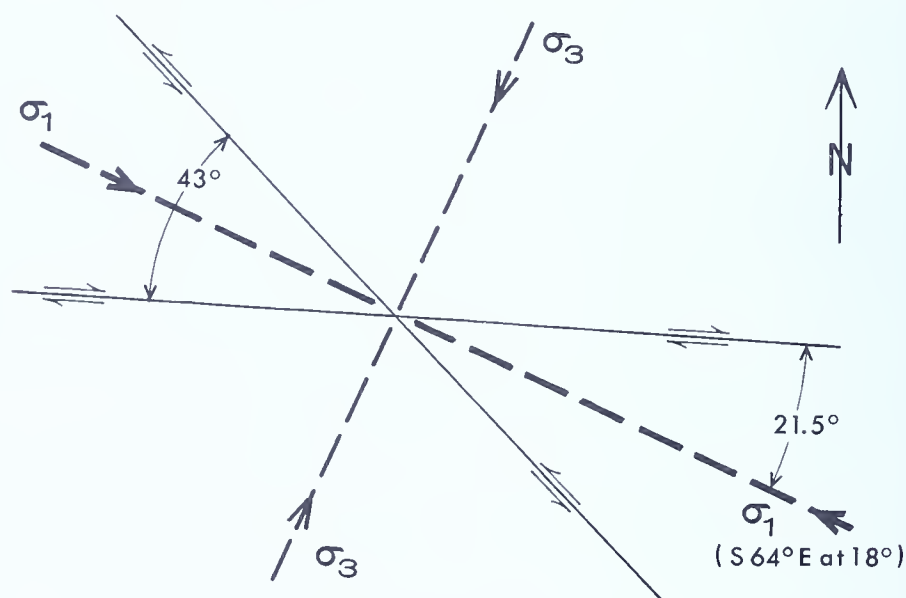
Six moderately large cross faults, excluding those already described along Little Scrub Ridge, are mapped in the quadrangle. A few smaller cross faults with displacement of 100 feet or so are mapped, but probably many more are present. As indicated by the absence of topographic deflection, the Cowan Gap fault is nearly vertical; the other cross faults are assumed to be nearly vertical also. Probably most of the cross faults have both dip-slip and strike-slip displacements: for example, the northeast side of the Cowan Gap fault has moved about 1,500 feet up and about 2,500 feet northwest relative to the southwest side. The cross faults may have been active during the period of folding. If so, the kind and even the sense of displacement may vary along a fault, the fault surface having acted as partition separating folding on both sides.

In Cove Gap, half a mile south of the quadrangle, fault offset, if any, does not exceed 100 feet. The Tuscarora-Juniata contact was surveyed on both sides of the gap and the strikes and dips of the contact were found to project on top of each other. There is evidence of a cross flexure in the gap; outcrops also display much fracturing and slickensiding on joint surfaces and thus indicate small-scale fault movements. Locally on the north side of the gap, the Tuscarora-Juniata contact is a small fault.

No offset of the contact between the Tuscarora and Juniata Sandstones was noted in the water gap of Rocky Hollow.

Small-scale cross faults or strike-slip faults with displacements of a few feet or less are present in many sandstone outcrops. Along State Highway 16 on the west side of Tuscarora Mountain, two sets of intersecting shear zones occur in the Juniata Sandstone. As indicated by the relative directions of movement recorded by slickensides, these intersecting shears are conjugate. For 15 pairs of conjugate shears, the strikes and dips of the fault surfaces and plunges of the slickensides were measured and plotted on an equal-area net. The angle 2α between the shear planes and also between the slickenside lineations was determined for each pair of measure-

ments. Hartman's angle, or the angle α between the greatest principal stress and the shear plane averages 21° (Fig. 4). Values as determined by the slickensides are essentially the same (Fig. 4). The average Hartman angle of about 21.5° is much less than the normally quoted value of 30° (Billings, 1954, p. 95), but is in the range of experimental determinations (Handin and Hager, 1957, p. 23). The acute bisectrix of the shear planes or slickenside lineations determines the greatest principal stress. Locations of the greatest principal stress are concentrated within about 5 percent of the total area of an equal-area net, and indicate that the greatest principal stress for the shears is *now* oriented approximately S 64° E @ 18° . The least principal stress is essentially horizontal and parallel to strike. These conjugate shears might have formed either early in the deformation when the rocks and the greatest principal stress were



A. Diagram showing average orientation of 15 pairs of shear planes. Map view of plane which strikes N 26° E and dips 18° E. The greatest principal stress (σ_1) and least principal stress (σ_3) are in the plane of the map; the intermediate principal stress is perpendicular to it.

Measurement made on	Hartman's angle (α)	Standard Deviation	Highest angle	Lowest angle	Coefficient of internal friction (β) $\beta = 90^\circ - 2\alpha$	Present orientation of greatest principal stress
Shear planes	21.07	4.90	28.5	15.5	49.86	S 63° E at 24°
Slickensides	21.77	4.13	27.5	16.0	46.46	S 65° E at 12°
Numerical average of both	21.42	4.52	28.0	15.75	47.16	S 64° E at 18°

B. Compilation of data from 15 pairs of fault plane measurements.

FIGURE 4. Small conjugate shears in the Juniata Sandstone. Hartman's angle (α) averages 21.5° . Measurements made along State highway 16 on west side of Tuscarora Mountain.

nearly horizontal, or late in the deformation when the rocks and the greatest principal stress were here locally inclined gently toward the east.

The Tuscarora Fault

The Tuscarora fault is named from exposures on the sides of Tuscarora Mountain. It is not the same as the "Tuscarora Mountain fault" of

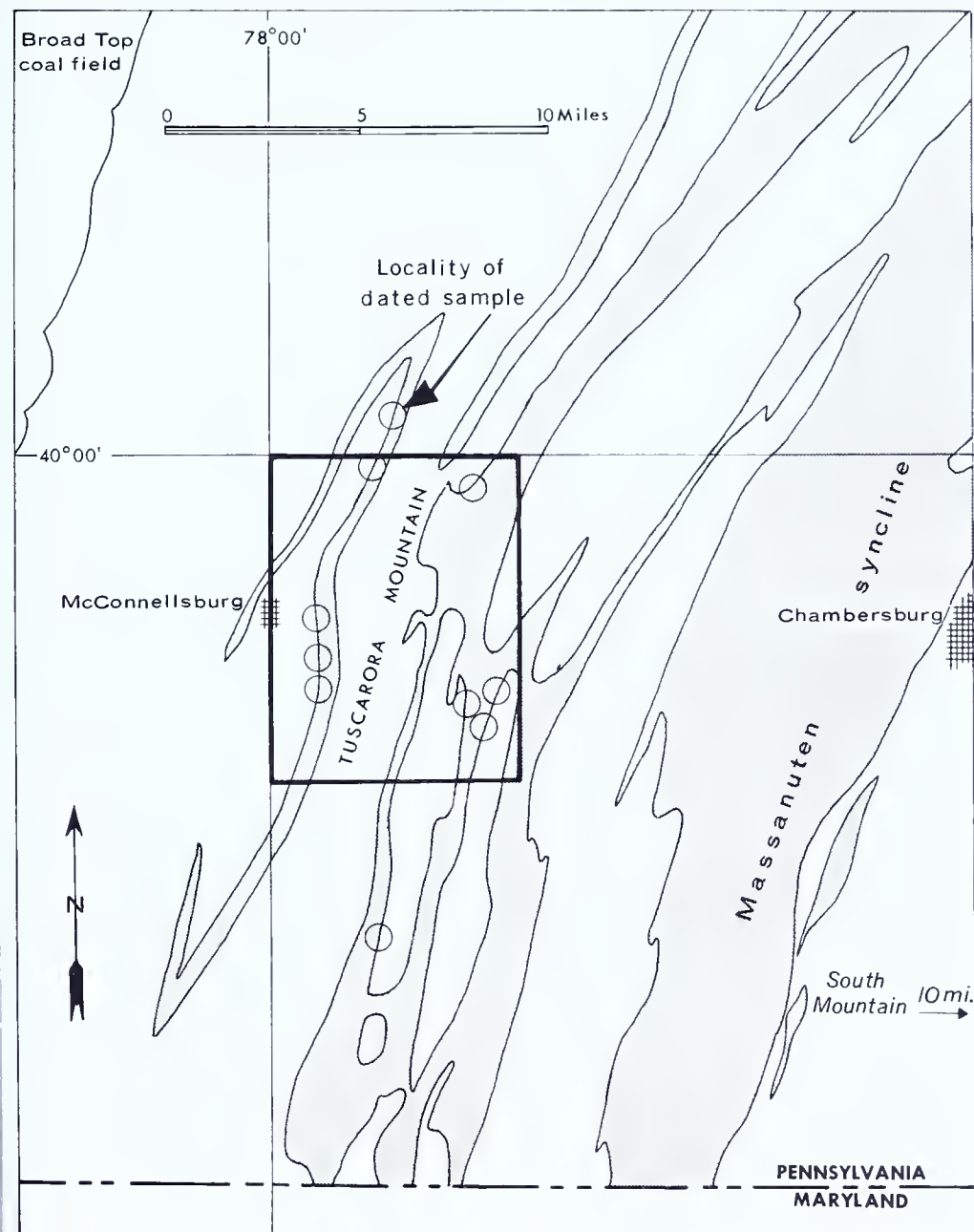


FIGURE 5. Observed localities of the Tuscarora fault mylonite (circles). Shaded areas represent Reedsville-Martinsburg shale outcrop belts. Blocked area is the McConnellsburg quadrangle.

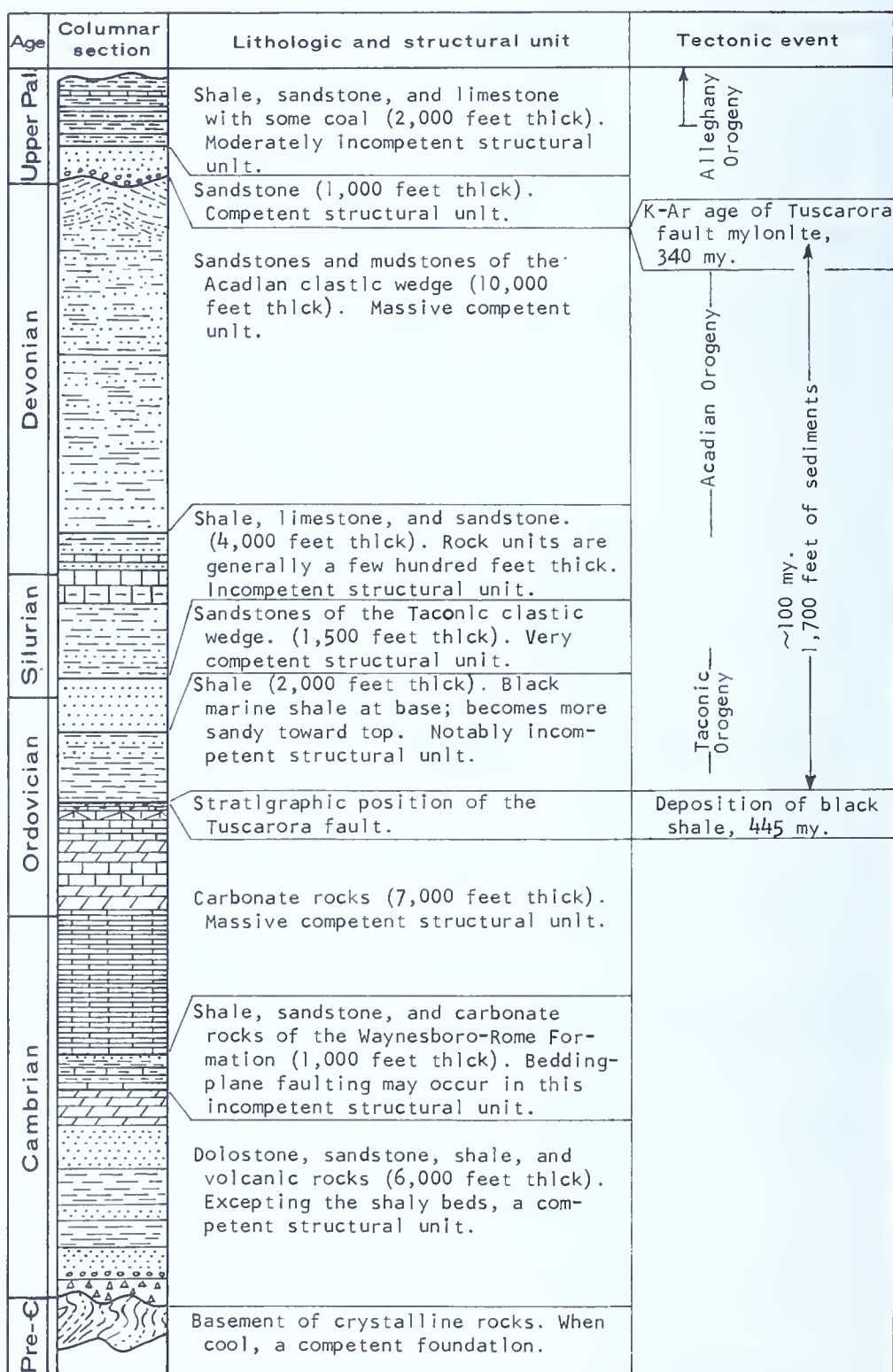


FIGURE 6. Geologic section of the Valley and Ridge province of the central Appalachians.

Stose (1909, p. 14). The Tuscarora fault is a bedding-plane fault marked by a thick mylonite zone near the base of the Reedsville Formation. Ten exposures of the mylonite were observed in or near the quadrangle (Fig. 5); exposures within the quadrangle are marked in Plate 1. About half of the exposures are remains of laborious excavations dug into the mylonite by prospectors who thought that the shiny black rock would turn to burnable coal at depth.

The position of the fault in the Paleozoic section is shown in Figure 6. As shown by the map pattern (Pl. 1) and the cross sections (Pl. 2) the Tuscarora bedding-plane fault has been folded into typical Valley-and-Ridge folds, including local overturning. It is interpreted in Plate 2 as cut by a number of later high-angle faults.

The mylonite occurs in rocks of Trenton age (upper Middle Ordovician). It overlies black shales and limestones of the Salona Formation and occurs in black graptolitic shales of the basal Reedsville Formation (Fig. 7). In McConnellsburg Cove the fault zone occurs along the Salona-Reedsville contact (Fig. 7). In the Mercersburg reentrant, the stratigraphic succession is almost the same, except that a few tens of feet above the fault there is about 50 feet of black limestone and shale which could be either a natural stratigraphic change, or part of the Salona Formation repeated by the Tuscarora fault (Fig. 7).

The Mylonite

The mylonite is a black, fine-grained rock, apparently derived from black, graptolitic shale. It breaks along shiny phyllitic surfaces and is a phyllonite. Both the shale and the phyllonite formed from it consist of clay- and silt-sized particles, and consequently no reduction in grain size is megascopically observable. An irregular foliation defined by the phyllitic surfaces curves through angles of more than 90° and commonly does not parallel the bedding of the inclosing rocks. At the locality pictured in Figure 8 the upper contact of the mylonite with the shale is very sharp; it follows the base of an inch-thick bed, then cuts diagonally across a few beds, and again follows the base of another bed. At other places, the contacts appear to be more gradational. The thickness of the mylonite at the locality shown in Figure 8 is about 15 feet; at other localities it appears to range from 5 to 20 feet.

The mineralogy of the mylonite and black shale, as determined from tentative X-ray and optical observations, is as follows: quartz—50 percent, illite—35 percent, large mica flakes—5 percent, and carbonaceous material—10 percent. Carbonaceous material in the mylonite consists of originally disseminated carbon and ground-up graptolites. Veins of calcite and, less commonly, pyrite occur in the mylonite. Thin sections show close-spaced anastomosing seams of clay and carbonaceous material in a quartz-silt

matrix. The quartz grains appear crushed by movement on the clayey seams.

Movement on the Tuscarora fault

The amount of movement on the Tuscarora fault is difficult to estimate. Little or no stratigraphic displacement has occurred across the fault in the McConnellsburg area. Movement along the bedding, however, may be great. The mylonite is similar in character and thickness to that

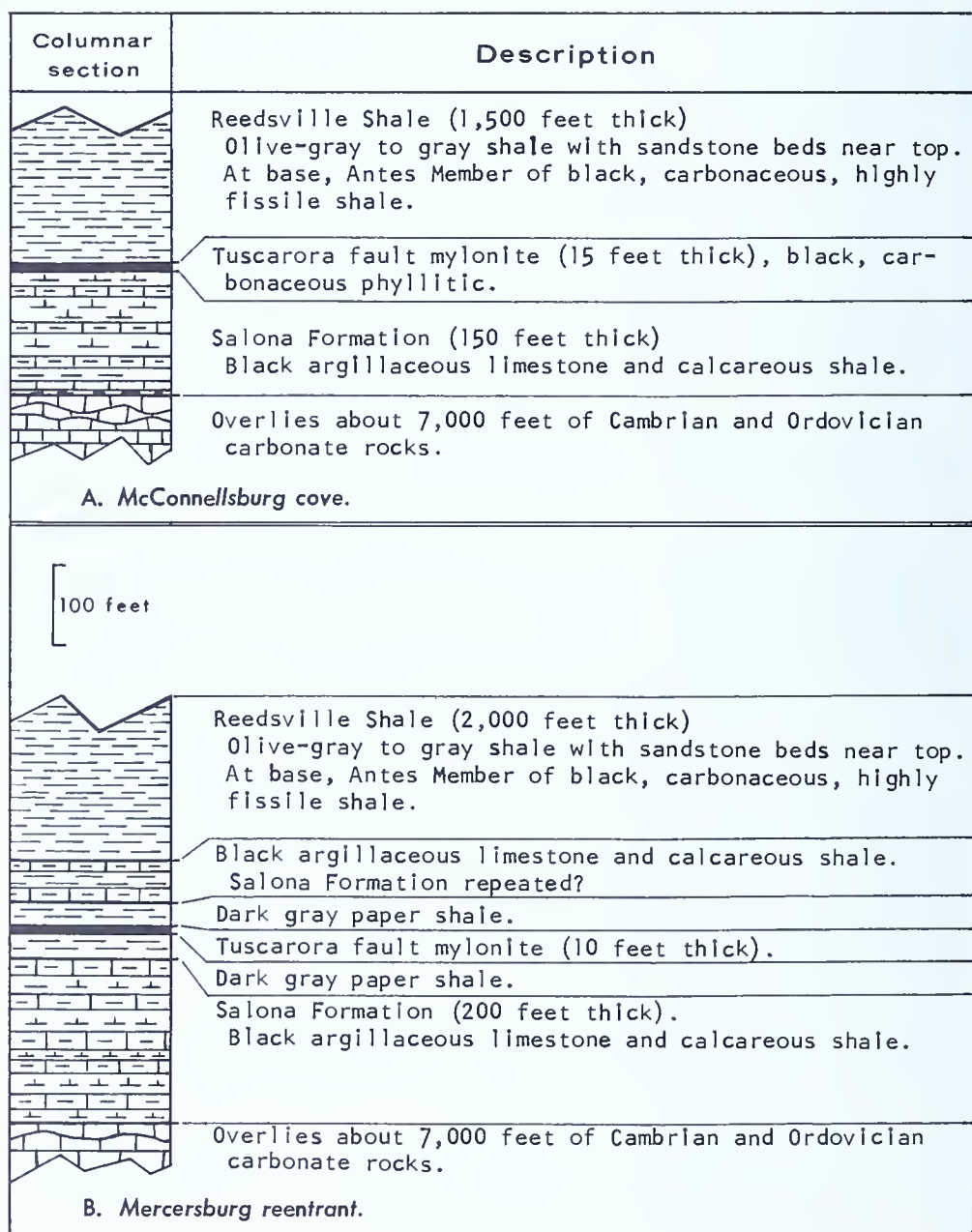


FIGURE 7. Columnar sections of the Ordovician (Trenton) rocks immediately above and below the Tuscarora fault.

exposed in the fault zone at Birmingham, Pa., where Moebs and Hoy (1959) show that there has been at least 2 miles of movement. The Tuscarora-fault mylonite is also similar to the few feet of "coal-like" mylonite reported by Young (1957) from the base of the Cumberland overthrust block in Virginia, where as much as 7 miles of movement has been demonstrated by Miller and Fuller (1954). Thus, by analogy, the mylonite of the Tuscarora fault may have been formed by miles of movement.

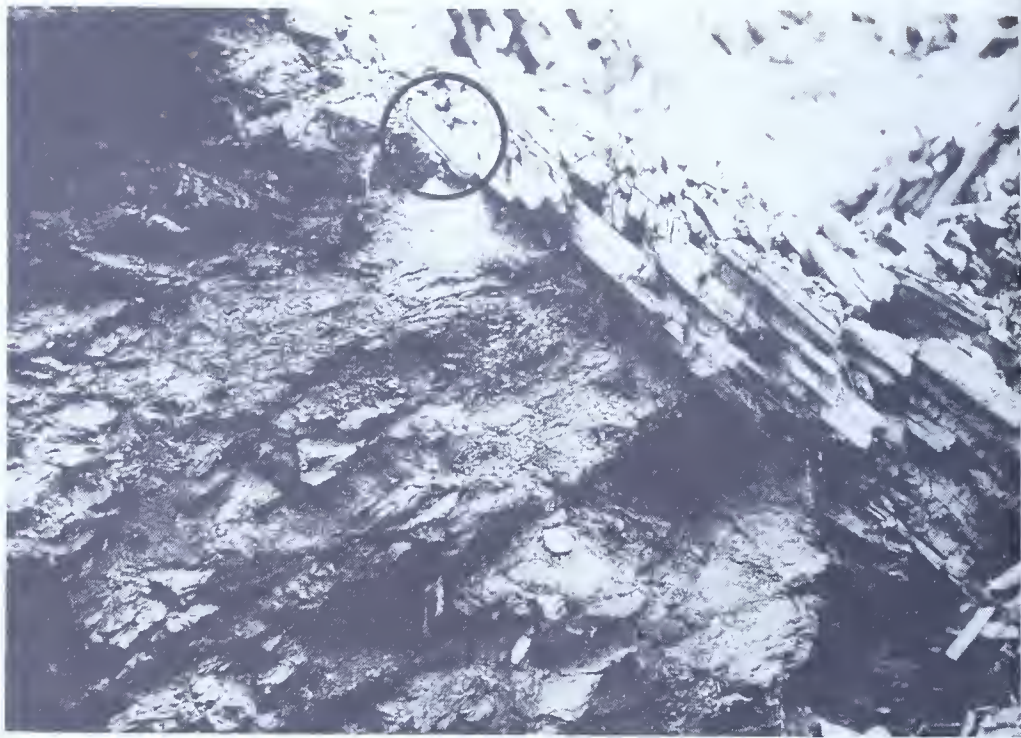
It might be postulated that concentric folding produced a very large amount of bedding-plane shear at the contact between the underlying carbonate strata and the overlying shale strata. According to the standard model of concentric folding, bedding-plane slippage of 1.6 times the thickness of the "bed" considered is possible. This model does not seem reasonable if the Cambrian and Ordovician carbonate strata are considered as one "bed" and the Reedsville Formation as another. Numerous incompetent shaly beds and partings both have above and below the mylonite zone, including more than 10 beds of middle Ordovician altered volcanic ash, would be expected to dissipate stresses by bedding-plane shear rather than transmit it to the zone of the Tuscarora fault. In addition, the two-bed concentric-fold model implies both shortening and lengthening of the strata adjacent to the fault by 20 percent; almost undeformed oolites in the carbonate rocks in McConnellsburg Cove suggest little body deformation of these rocks (Cloos, 1949, p. 883).

With appropriate exposures, field observations could determine if bedding-plane shear associated with concentric folding were involved. If produced by concentric folding, sense-of-shear phenomena on the two limbs of a fold should be in opposite directions. Unfortunately, no clear evidence of sense-of-shear phenomena was found. Furthermore, bedding-plane shear produced by concentric folding should not take place along the axes of folds and thus mylonite should be absent there. Unfortunately again, no exposures were found along the axes of folds at the stratigraphic horizon of the Tuscarora fault.

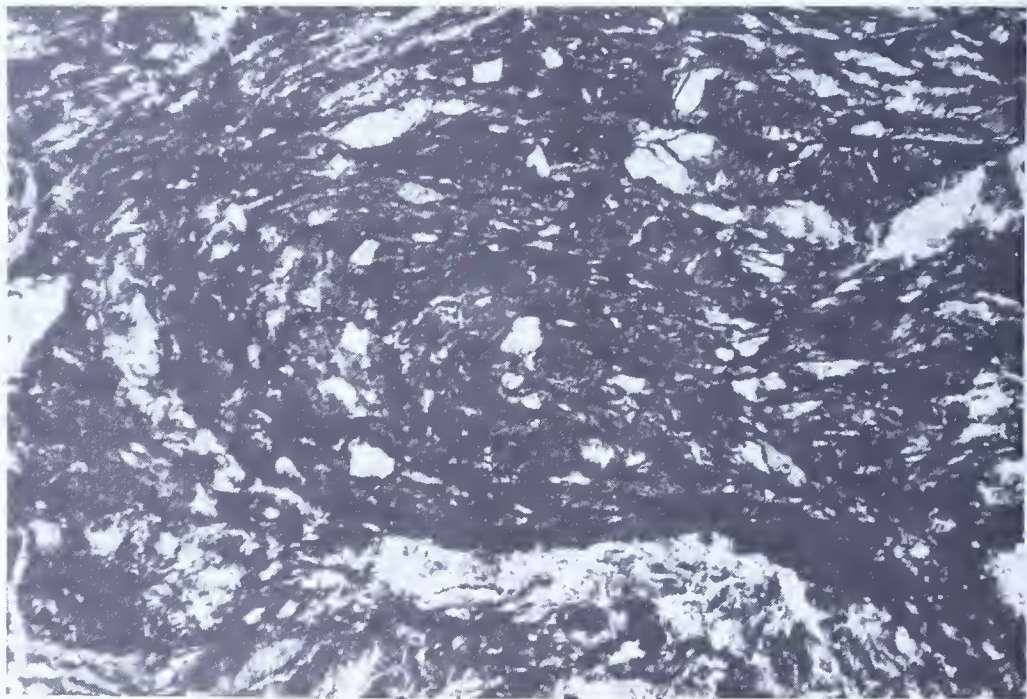
It is suggested that there was movement, probably to the west, of the sedimentary rocks above the Tuscarora fault some time after deposition of the Reedsville Formation and before the Alleghany concentric folding of the Valley and Ridge. Of course, some later minor movement in the zone of the fault, as well as along many other bedding planes, is to be expected as a normal part of the Alleghany folding.

Radioactive Age Determinations

Samples from the mylonite and overlying black shale were collected in McConnellsburg Cove just north of the quadrangle (Lat 40°12.3'; Long 77°56.7'). These samples were taken only 10 feet apart on the borrow-pit face pictured in Figure 8. Age determinations by the K-Ar method



A. Mylonite and overlying black shale at locality selected for K-Ar age determination. Note sharpness of contact. Mylonite about 15 feet thick. Circled pocketknife indicates scale.



B. Photomicrograph of Tuscarora fault mylonite. Shear zones delimited by dark bands. In this case the shear zones are deformed into tight folds; in other places they are planar. Diagonal of photograph about 2 mm.

FIGURE 8. Tuscarora fault mylonite.

were made by R. L. Armstrong at Yale University (See Armstrong, 1964, for discussion of method of analysis). The following whole-rock ages were obtained:

black shale— $425 \begin{smallmatrix} +60 \\ -20 \end{smallmatrix}$ million years (m.y.);

mylonite— $340 \begin{smallmatrix} +50 \\ -15 \end{smallmatrix}$ m.y.

The younger age for the mylonite indicates a loss of argon from the shale due to heat and strain accompanying movement on the Tuscarora fault. *If* all the contained argon was released at the time of movement, *and if* no argon has been subsequently lost, the date of 340 m.y. indicates how long ago movement ceased.

The stratigraphic horizon of the fault is immediately above a number of altered volcanic ash beds whose age of 445 m.y. has been well determined in the southern Appalachians (Adams and others, 1958). Consequently a more reliable age for the shale overlying the fault is about 445 m.y. (Problems in dating shales are discussed in Hurley and others, 1961, and Bailey and others, 1962).

The age of 340 m.y. for the mylonite correlates with a late part of the Acadian Orogeny (Woodward, 1957; King, 1959, p. 60) and is very close to the Devonian-Mississippian boundary which Kulp (1961, Fig. 1) places at 345 m.y.

Conclusion

Most of the deformation in the Valley and Ridge province is commonly ascribed to an orogeny which occurred near the end of the Paleozoic Era, the Alleghany Orogeny of Woodward (1957, p. 2326). In addition, the upper Ordovician Taconic Orogeny has been shown to have deformed rocks within the Great Valley in eastern Pennsylvania as far southwest as Harrisburg (Platt and Carswell, 1963; Maxwell, 1962; Drake, 1960, and references therein).

Only recently has definite evidence of an Acadian Orogeny in the central Appalachian Valley and Ridge province come to light. In the western part of the Anthracite basin, Trexler, Wood, and Arndt (1961), and Hoskins (personal communication, 1963) report an angular unconformity beneath the lower Mississippian Pocono Formation at distances of up to 20 miles northwest from the Great Valley. Dips of up to 75° and removal by erosion of more than 2,500 feet of strata (Gordon Wood, spoken communication, 1963) occur locally beneath this unconformity, indicating considerable Acadian deformation of this part of the Valley and Ridge. The radioactive age of the mylonite correlates well with this unconformity. Elsewhere in the central Appalachians no unconformity of this age is presently recognized, but detailed mapping and study, such

as recently done around the Anthracite basin, might reveal a more extensive Acadian deformation. Perhaps there is an Acadian unconformity in the Broad Top syncline.

Three other aspects of the geology of the central Appalachians might be associated with an Acadian deformation. (1) The thickest part of the upper Devonian Acadian clastic wedge occurs in central and southern Pennsylvania (Jones and Cate, 1957, Pl. 7; King, 1959, Fig. 34). Both the uplift of the source area of these sediments and the rapid deposition of this thick clastic wedge might be related to movement on the Tuscarora fault. (2) In the Baltimore area, which is 75 miles east of the quadrangle, radioactive age determinations indicate a cooling about 300 to 350 m.y. ago (Davis and others, 1958, p. 177; Tilton and others, 1959, p. 157; Davis and others, 1961, p. 193). Along the Susquehanna River in southeastern Pennsylvania, K-Ar age determinations indicate a metamorphic cooling about 330 m.y. ago (Lapham and Bassett, 1964). These heating and cooling episodes suggest crustal movements east of the quadrangle during late Devonian and Mississippian time. (3) In the Valley and Ridge province of Maryland, Silurian and Devonian rocks that were deformed during the Alleghany Orogeny show pre-folding bedding-plane slips and wedges (Cloos, 1960, p. 116). These structures were formed during either the Acadian Orogeny, or an early part of the Alleghany Orogeny.

The stratigraphic position and the radioactive age of the Tuscarora fault can be rationalized by application of the theory of fluid pressures in overthrust faulting (Hubbert and Rubey, 1959). The fault occurs near the base of an originally water-rich section of shale 2,000 feet thick (Fig. 6). Some water was retained in this relatively impermeable shale, and during compaction abnormally high fluid pressures might be expected, especially near the base of the shale. A good foundation for movement is provided by the underlying competent sequence of Cambrian and Ordovician carbonate rocks. Radioactive age determinations suggest movement on the Tuscarora fault 100 m.y. after deposition of the basal Reedsville Shale. At this time, 17,000 feet of sediments had been deposited above the horizon of the fault (Fig. 6), and the Acadian clastic wedge was being deposited at a rate about 4 times greater than the pre-upper Devonian sediments above the horizon of the fault. This rapid loading during late Devonian time is expected to have accelerated normal compaction of the underlying sediments, and increased fluid pressures at the base of the Reedsville Formation. Consequently, near the end of Devonian time, abnormally high fluid pressures at the base of the nearly flat-lying Reedsville shale may have greatly reduced the vertical stress transmitted by the rock, and thus diminished the frictional resistance opposing horizontal movement of the overlying sedimentary blanket. At this time, either lateral thrust imparted from an eastern tectonic source,

or gravity acting down a dip, is expected to have resulted in movement of this three-mile-thick sedimentary blanket.

Changes with Depth

What happens at depth to the surface folds and faults of the McConnellsburg quadrangle? Unfortunately structure mapped at the surface can be projected downward for only a few thousand feet below which the positions of units become very speculative; at a depth of a mile or more only the *kind* of structure rather than approximate positions of rock units can be reasonably hypothesized.

Disharmonic folding of incompetent rocks sandwiched between broadly folded competent rocks is well displayed by the Silurian and Devonian shale in the nearby Loysville quadrangle (Miller, 1961) and Mifflintown quadrangle (Conlin and Hoskins, 1962), and probably occurs also in the Ordovician Reedsville-Martinsburg shale.

In the Valley and Ridge province in Pennsylvania, large thrust faults appear to be more common in Cambrian and Ordovician carbonate rocks than in the overlying rocks.

A low-angle thrust fault involving middle Cambrian and younger rocks with at least two miles of displacement (Moebs and Hoy, 1959, p. 1085-1087) is exposed in a window 50 miles north of the quadrangle at Birmingham on the Nittany arch.

Comparison of the Valley and Ridge province in the central Appalachians with other folded miogeosynclinal rocks such as the Jura Mountains, the Rocky Mountains in Alberta, and the Valley and Ridge province in the southern Appalachians strongly suggests the possibility of a décollement zone or bedding-plane fault at depth. The most likely basal horizon of movement is the shaly Waynesboro or Rome Formation (upper Lower Cambrian) (see Gray and others, 1960; Rodgers, 1953, p. 162; King, 1959, p. 44-46). The depth of the postulated décollement zone beneath the Broad Top flat-bottomed syncline, 20 miles northwest of the quadrangle, is about 27,000 feet below sea level. In comparison, upon a basis of stratigraphic thicknesses, the depth of the postulated décollement zone beneath the major synclines within the McConnellsburg quadrangle is only 10,000 feet below sea level. Thus it appears that either the postulated décollement zone descends in level 17,000 feet along an average slope of 90° between the quadrangle and the Broad Top syncline, or there is a structural thickening of post-Waynesboro rocks beneath the quadrangle by 17,000 feet (a factor of 2), or that there is a combination of the two.

Structural thickening beneath the quadrangle may be accomplished by imbricate thrust faults that repeat large parts of the section. Within

the Valley and Ridge province this sort of phenomena is being encountered rather commonly in deep wells, where a few thousand feet of section is repeated one or more times. Surface mapping has not been able to predict these faults, and by negative analogy, this sort of faulting might be present beneath the McConnellsburg quadrangle. The hypothetical structure section BB' (Pl. 2) shows a low-angle fault at a depth of about 10,000 feet which repeats the entire Cambrian and Ordovician carbonate section. There is little evidence for or against this interpretation. A cross section that accounts for the stratigraphic low at the Broad Top syncline by a concordant low in the basement is given in Rodgers (1953, Fig. 2).

Other décollement zones probably occur above that postulated in the Waynesboro Formation. As discussed in the section on the Tuscarora fault, bedding-plane movement at the base of the Reedsville Formation may have occurred near the end of the Devonian Period. Miller (1961, p. 42) notes a décollement zone at the base of the Marcellus Formation (Lower Devonian). Calculations by the method given in DeSitter (1956, p. 189-190) based on folds in and near the quadrangle indicate a décollement zone at a depth of only one mile, although the model for this calculation may not be entirely applicable to folds within the quadrangle because it does not consider the effect of thrust faults. In the process of drawing cross sections by the concentric fold method, one finds that most of the anticlinal structures tend to become sharply cusped at a depth of one mile. Thus there appears to be the probability of other zones of décollement or bedding-plane faulting above a basal décollement in the Cambrian Waynesboro Formation, although perhaps the known thrust faults may account for part of the closure of the concentric folds.

Age of Deformation

Although the Taconic Orogeny (probably Late Ordovician) deformed rocks within the Valley and Ridge province in eastern Pennsylvania and New York, it apparently did not deform the rocks of the Valley and Ridge province in southern Pennsylvania. Acadian orogenic movements affected parts of the Valley and Ridge province in the central Appalachians; the evidence for this deformation is discussed under "The Tuscarora fault."

Most folds and high-angle faults in the quadrangle are part of structures which can be traced into deformed Carboniferous rocks and therefore most of the deformation of rocks within the quadrangle is referred to the Alleghany Orogeny, which occurred toward the end of the Paleozoic Era (Late Mississippian? to Triassic? time).

MINERAL RESOURCES

Although the quadrangle does not contain any large concentrations of especially valuable mineral resources presently being exploited (such as coal beds or metal ores), it does contain a diversity of mineral resources that are economically important and are or could be utilized.

High-calcium limestone is the most extensively quarried rock in this part of the Appalachians and is used chiefly as crushed rock and agricultural limestone. The upper part of the Saint Paul Group (New Market Formation) is the most commonly quarried rock, mainly because it is pure lime-mudstone that is readily broken and crushed. But any of the Cambrian or Ordovician carbonate rocks could be used as serviceable crushed rock or agricultural "limestone". The dolostone units of the Beekmantown Group are a good source of the double carbonate of magnesium and calcium. The numerous quarry symbols on the map with "Ls" beside them (Pl. 1) represent small inactive or rarely used limestone quarries. Because of modern large-scale quarrying and low-cost trucking, most limestone is taken from a few large quarries, which are located in the Cumberland Valley outside the quadrangle. Within the southeast corner of the quadrangle, suitable large quarry sites might be located in any one of the three wide outcrop belts of Saint Paul Group.

Building stone can and has been obtained from the bluish-gray Saint Paul Group or other carbonate rocks, the light-tan or white Tuscarora Sandstone, and the deep-red "iron" sandstones of the Rose Hill Formation.

Sand and ganister can be obtained from the Tuscarora Sandstone. A surficial deposit of quartz sand is commonly formed where the Tuscarora Sandstone is deeply weathered beneath rather gentle slopes, as at the sand pit on Tuscarora Mountain above McConnellsburg.

Rock for local roads and fill is obtained (see quarries marked "Sh", Pl. 1) from the Reedsville shale or shale-chip rubble derived from Reedsville shale. The shale breaks up readily into pebble-sized fragments and can be easily quarried by one man with a tractor-scoop. It eventually weathers to clay, thus making the rock unsatisfactory for some more permanent installations.

Iron ore has been mined from the Centre "iron" Sandstone Member of the Rose Hill Formation near Buchanan Summit. The iron oxide content of the Centre Member is about 15 percent (Miller, 1961, p. 44). This large potential source of iron can not be mined profitably unless a low-cost method is developed for processing low-grade ores containing quartz grains.

During the last century, surficial deposits of iron ore were mined at many places in and near the quadrangle; such places are shown on Plate

l by a quarry symbol with "Fe" beside it. Because these old workings are now partly filled in, slumped and overgrown, few observations of the mines can now be made, and the reader is referred to descriptions by those who saw many of the mines when they were still exposed (Rogers, 1858, p. 322, and mines near the quadrangle, p. 432, 728, 731, 733; d'Invillers, 1887, p. 1491-1494 and mines near the quadrangle, p. 1494-1501; and Stevenson, 1882, mines near the quadrangle, p. 292, 296, 298, 316, 317, 318, 319, 327, 330).

One feature, not previously noted, was observed at the Mt. Pleasant bank, located along the Path Valley fault, 500 feet south of Bricker Run. High on the west bank of the southernmost large pit, small veins of pyrite occur in a light-gray clay. The pyrite appears as small crystals that range in size from aphanitic to a few millimeters. The clay is mostly illite with some(?) kaolinite and is rich in quartz silt; it has an X-ray diffraction pattern similar to that of the much darker Reedsville shale. The Mt. Pleasant bank overlies the Reedsville shale, some of which is exposed in barren zones of the mine. Consequently this iron ore deposit differs from most of the other surficial iron ore deposits of the Valley and Ridge province which characteristically overlie and are genetically associated with carbonate rocks. The origin of the pyrite and its relation to the iron ore deposits might be explained in two ways.

1. Hydrothermal solutions may have deposited pyrite and altered the shale during or following the time of movement on the Path Valley fault. The solutions need not have originated from a magmatic source, but could have come from warm connate water in the iron-bearing Reedsville shale or other shales. (Pyrite is also present in the mylonite zone of the Tuscarora fault.) Subaerial weathering of this pyrite-rich fault zone would oxidize the pyrite, and the iron thus released would be precipitated as goethite, hematite, and limonite. A basic environment favorable for the retention of iron might be provided by ground-water solutions upwelling along the fault from carbonate rocks that underlie the Reedsville shale (Pl. 2, Section AA').

2. The pyrite may have been deposited by surficial waters in contact with a strong reducing agent, as was the pyrite deposit noted by Lewis (1881, p. 284) around an ancient lignite. No lignite or organic remains were found in the Mt. Pleasant bank. If pyrite were deposited by surficial waters, iron ore could be formed by subsequent oxidation of the pyrite, or by deposition initially from iron-bearing surficial waters in a basic and slightly reducing environment.

Black nodules of manganese oxide are common in the clay at the Mt. Pleasant bank.

Another feature noted that bears on the origins of surficial accumulations of iron oxide is the encrusting of outcrops of calcareous, carbona-

ceous shale with limonite. Surface and ground water have dissolved iron from bedrock upslope and upon contact with the basic and reducing environment of the calcareous, carbonaceous shale have precipitated iron. Apparently much of the iron ore mined at the Noreast mine in Bear Valley was of this variety.

Clays from fresh or weathered Reedsville shale and Rose Hill shale are available within the quadrangle for brick and tile manufacture. Red, white, orange, and purple clays for modeling and possibly industrial use are present along the Path Valley fault, notably where it crosses the stream below Cowan Gap. Thick accumulations of poorly sorted residual clay are present beneath the roundstone diamicton where it overlies carbonate and to a lesser extent shale bedrock.

Unsorted roundstone diamicton (Pl. 3), which occurs in the lowlands throughout the quadrangle, is good earthfill, noted for its high initial compaction.

The greatest mineral resource of the area is the soil. The limestone and shale soils of the valleys support rich farmlands, and the stony soils of the mountains support stands of scenic hardwood timber (see Higbee and others, 1938, and reports on file at the Soil Conservation Service, McConnellsburg, Pa.).

Natural gas or oil may be present in rocks beneath the quadrangle. Although much of the area has been leased and seismic surveys have been run, no wells have been drilled. The probability of complicated structures at depth separated from the rocks at the surface by low-angle faults makes the location of wells a problem. Nevertheless, anticlinal structures and potential fault traps are present at depth. Suitable reservoir rocks are not known but may be present, for little is known about reservoir rocks in the Cambrian and Ordovician strata. The sandy zones in the Conococheague Formation and Beekmantown Group(?) may contain gas or oil. The Silurian, Devonian and Carboniferous rocks which serve as reservoir rocks in areas west of the quadrangle, are only present in synclines within the quadrangle, unless they are repeated by faults at depth, a situation which is quite improbable. Gas or oil might be found below the postulated intermediate décollement zones.

Water resources in the quadrangle are adequate for present needs. Numerous springs issue from the shale and sandstone on the ridge flanks. Surface streams are common except over limestone bedrock. Wells drilled above limestone bedrock encounter water at 75 feet or so. Wells spudded in roundstone diamicton may pass through more than 100 feet of clayey residuum before reaching water in the underlying bedrock. No alluvial deposits thick enough to serve as a source of water are present, except possibly in a few places along West Branch.

PART 2—

SURFICIAL GEOLOGY AND GEOMORPHOLOGY

INTRODUCTION

Less than 2 percent of the area of the McConnellsburg quadrangle consists of exposed bedrock. Elsewhere the area is mantled by a regolith of residium, colluvium, and alluvium. This regolith is of primary importance for an understanding of the erosional history of the region. Thirteen types of regolith are recognized and described, and seven map units are shown on the surficial-geology map of the McConnellsburg quadrangle, Plate 3. A detailed study was made of a roundstone diamicton that mantles extensive areas along the larger streams. The residium and much of the shale- and limestone-derived colluvium are briefly described in the section on weathering and topography under "Topography".

The topography is well adjusted to the structure and stratigraphy of the bedrock. Most gaps and sags are related to structures. Topographic surfaces formerly believed to represent the Kittatinny and Harrisburg peneplains, or "lowlands of denudation" Davis (1889, p. 425-427), may be simply part of a normal topography developed during single-cycle erosion on bedrock of the given character.

CLIMATE AND VEGETATION

Like the rest of the central Appalachians, this area has a humid-temperate climate. Mean annual precipitation is 40 inches and mean annual temperature is 52°F. Monthly averages of precipitation, and minimum, maximum, and average temperature as recorded in the Cumberland Valley at Chambersburg are presented graphically by Figure 9. Since maximum relief in the McConnellsburg quadrangle is about 2,000 feet, there is considerable local variation in the climate. During Pleistocene glacial ages a more rigorous climate must have existed in this area inasmuch as the outer limit of glaciation lies only 70 miles north.

The fertile soils of lowland areas provide productive farmlands for corn, grain, and stock, and orchards of peaches, apples, and cherries. The stony soils in mountainous areas are favorable for forest growth, and support stands of northern hardwood and oak.

High-intensity precipitation—. Probably high-intensity precipitation is an important factor in the erosion of this mountainous area. Hack and Goodlett (1960) made a study of an area in the Appalachians of Virginia that was subjected to a "violent rainstorm of rare frequency. . . . The storm caused something over 100 landslides, tore up the bottoms of many valleys and destroyed hundreds of acres of forest land" (p. 42). Rainfall in this storm is known to have exceeded 7 inches and, in the area of maxi-

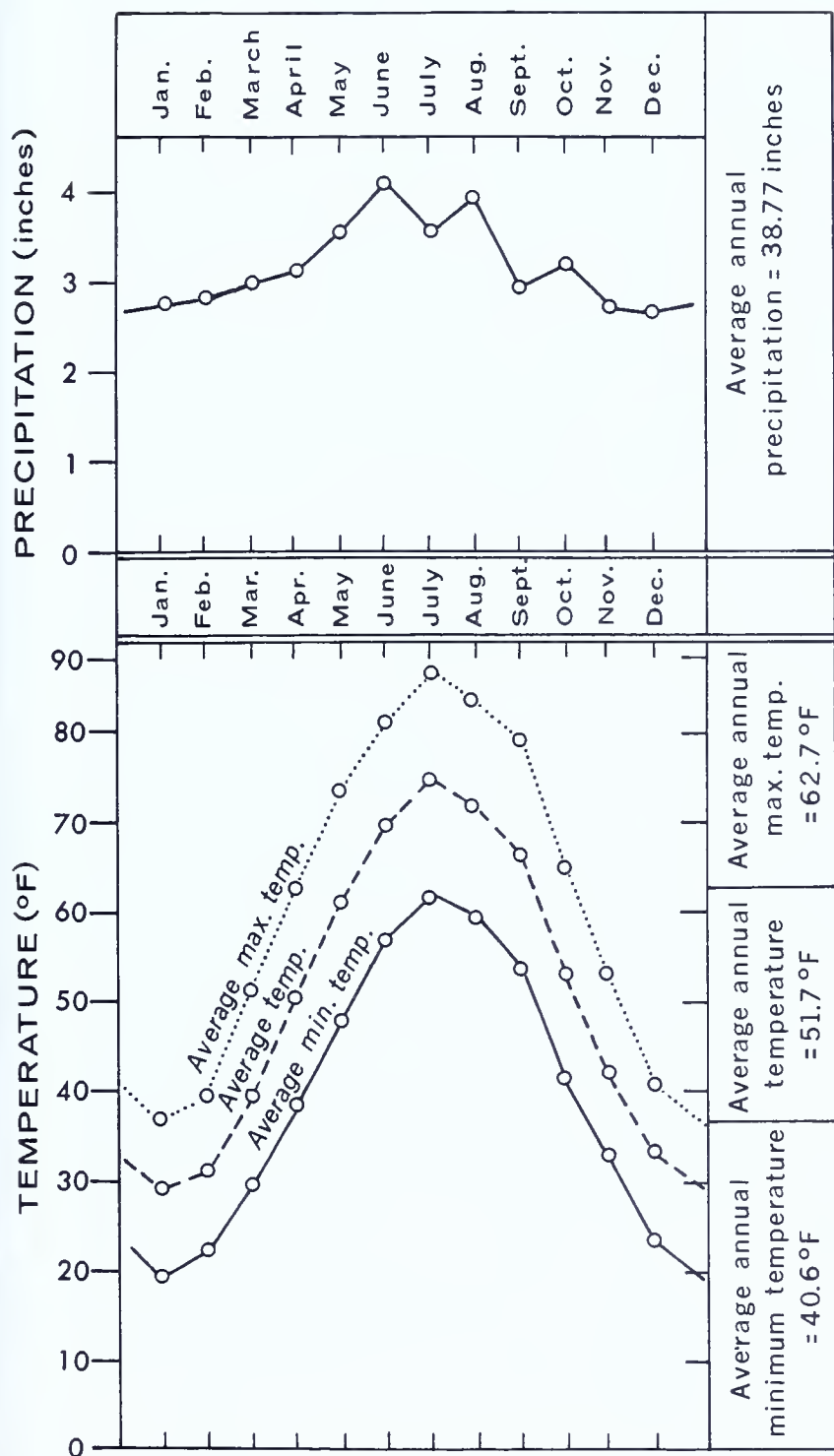


FIGURE 9. Graph of average monthly precipitation and temperature, Chambersburg, Pa. Chambersburg is 10 miles east of the McConnellsburg quadrangle, in the Great Valley at an altitude of 650 feet. After Martin (1930).

mum damage, possibly equaled 30 inches in a 24-hour period. (Hack and Goodlett, 1960, p. 42.) No similar storms and their effects have been observed in the McConnellsburg quadrangle, but climatic observations suggest such storms are likely to occur. At Smethport, Pennsylvania, more than 30 inches of rain fell in 4½ hours; during another storm at Concord, Pennsylvania, 16 inches of rain fell in 3 hours (Jennings, 1950, p. 4). The Climatic Summary of the United States (Martin, 1930, Section 88) makes the general statement that "the southern portion . . . [of central Pennsylvania] is subject to severe thunderstorms; heavy local rains amounting to 5 or 6 inches in 24 hours and to as much as 8 or 9 inches for a single storm have been recorded in many instances."

Frost action—. The importance of frost action as a geologic process is well established (see Rapp, 1960). In this area about 100 days occur annually with a minimum air temperature below freezing (Martin, 1930, section 88). As shown in Figure 9, average monthly maximum temperatures are at least plus 5°F; so it can be assumed that at present there are about 75 surface frosts a year. It is not known how many times a year the ground freezes to a depth of more than a few inches. At present the geologic work done by frost probably varies significantly between valleys and mountains. During glacial periods frost action was surely more severe than it is at present.

TRANSPORTED REGOLITH

Accumulations of transported debris characteristically rich in coarse-grained clasts mantle mountain sides and extend along streams out into the main axial valleys. In places coarse-grained clasts overlie bedrock of rock type different from that of the clasts; the source of the clasts is bedrock that crops out upslope. In other places the clasts are part of a mantle that obviously has moved a short distance down a steep slope, but has not moved far enough so that the clasts differ lithologically from the bedrock beneath. Two kinds of transported regolith are recognized according to the shape of the coarse-grained clasts: angular regolith and alluvium.* The angular debris is described first, for chronologically a clast begins as a sharpstone on the mountain slope; later it becomes a roundstone along a stream.

* The terminology adopted for the coarse-grained clasts is that given in Dunbar and Rodgers (1957, p. 164).

Sharpstone— individual angular fragment

Roundstone— individual rounded fragment

Rubble— unconsolidated aggregate of angular fragments

Gravel— unconsolidated aggregate of rounded fragments

(The word rubble is not intended to imply a hodgepodge of materials, but simply an accumulation of angular rock fragments larger than 2 mm.)

ANGULAR REGOLITH

Angular regolith is divided into two categories on a basis of topographic position: rubble on interfluves and rubble on valley floors. The major divisions of rubble, as well as the lesser subdivisions, grade into one another. All the angular debris studied occurs in the immediate proximity of the mountains. The following discussion of angular regolith follows the movement of sharpstones from their origin on ridge crests, downward over the slopes to the mountain valleys.

Rubble on Interfluves

Sheets of rubble mantle the mountain slopes. Rubble is derived from bedrock by weathering, especially frost action, and is then transported downslope by mass-wasting. A matrix of finer material commonly present between the sharpstones is derived by weathering of bedrock and regolith. Rubble on interfluves is subdivided on the basis of surface slope, presence or absence of a matrix, and size of clasts.

Screes

For this report a scree is defined as an accumulation of coarse-grained rubble on a slope steeper than 20° .

Screes form sizeable bodies along more than 75 percent of the length of the sandstone ridges. Most screes are covered by a canopy of large trees, and consequently are not apparent on aerial photographs or when viewed from a distance. Screes lacking a brush or tree cover occupy less than 10 percent of the aggregate ridge length. Bands of scree 50 to 500 feet wide occur on and just below the outcrop belt of Tuscarora Sandstone and, to a lesser degree, other sandstones both on the ridges and in the gaps. Some screes are elongate downslope, and are similar to the stone stripes observed elsewhere in the Appalachians. Generally screes are present only on topographic surfaces inclined opposite to the dip of the underlying rocks. For this kind of slope, the name anti-dip slope is proposed. Along Little Scrub Ridge where bedrock is vertical, screes occur on both sides of the ridge. Field measurements of the slopes of screes in the quadrangle average about 25° and rarely exceed 30° . The screes are generally not surmounted by cliffs. Sliderock (the sharpstones composing the scree) consists dominantly of light-gray Tuscarora sandstone and to a lesser extent of Juniata sandstone. The sharpstones at the surface average about one foot in diameter, although some fragments are 10 feet or more in diameter. Most surfaces of the sharpstones, especially those of the larger blocks, are either joint or bedding planes. Sharpstones on the surfaces of screes are commonly unstable and move underfoot. At and near the surfaces of the screes no matrix occurs between the sharp-

stones; consequently, the screes support little vegetation except lichens and deep-rooted trees and vines. In places the lichen cover on the sharpstones is absent or poorly developed, suggesting recent movement. The thickness of the screes is generally greater than 5 feet and probably less than 25 feet.

Sliderock is generally produced from bedrock by frost wedging (Rapp, 1960, p. 106). The origin of sliderock near glaciated areas is commonly attributed to increased frost action associated with a periglacial environment. In the McConnellsburg quadrangle, movement is now occurring within the screes. This is indicated by (1) local absence of lichen cover on sharpstones, (2) unstable sharpstones, and perhaps (3) absence of forest on parts of the screes. Slopes of screes in the Rocky Mountains generally exceed 30° (Behre, 1933, p. 623). The fact that slopes of the screes in the McConnellsburg quadrangle average only 25° may indicate that the rate of sliderock formation is less than the rate of removal, and that sliderock formed earlier in a periglacial environment is now being diminished by mass-wasting. Frost action may still be important, not so much in producing the screes as in helping to move the sliderock and other regolith downslope. Although the presence of screes may suggest a periglacial effect, it does not prove one. To do so it must first be conclusively demonstrated that sliderock is not now forming at a significant rate. Screes are not generally surmounted by cliffs or even by sizeable exposures of bedrock, so that the constituent sharpstones must be derived from bedrock beneath a mantle of sliderock. Consequently most sharpstones do or did not fall onto a scree from above, but must be or have been contributed by movement of sharpstones outward and away from the underlying bedrock.

In this area the resistance of the bedrock and angle of slope appear to be the factors localizing each occurrence. Because of the north-south strike of the ridges, sliderock occurs predominantly on east- and west-facing slopes, but is present locally both on the north- and south-facing slopes of the water gaps. Apparently compass orientation is not important, for sliderock is present on both northwest and southeast sides of Little Scrub Ridge, where dip of the bedrock is vertical.

Block Fields

As used in this report, a block field is a sheet or "field" of coarse-grained rubble with little or no matrix on slopes less than 10° . Sharpstones in block fields are the same shape, size range, and composition as those in screes.

Block fields occur on gently sloping surfaces near outcrop belts of sandstone. Commonly they grade either upslope or downslope into screes. Combinations of structure and topography that favor the occurrence

of block fields are (1) broad anticlinal or synclinal mountains, and (2) sandstone outcrops positioned by faulting or folding immediately above rocks that underlie nearly level topography. Homoclinal ridges that dip more than 10° do not sustain block fields because the slopes near the sandstone outcrops are too steep.

Most of the block fields have irregular surfaces displaying basins and mounds. Basins one to 4 feet deep and 15 to 30 feet in diameter are well developed at the following localities:

Cowan Gap: Along the trace of a cross fault in Allen Valley, 1000 to 1500 feet $N25^\circ E$ from the east abutment of Cowan Gap Lake Dam.

Big Mountain North: At the intersection of the ridge crest and the trace of a synclinal flexure, 1700 feet $N5^\circ W$ from Big Mountain Fire Lookout.

Big Mountain South: On an elevated gently sloping dip slope of Tuscarora Sandstone, 1000 to 1500 feet $S20^\circ E$ from Big Mountain Fire Lookout.

On these fields the slope does not exceed 5° . Basins with vertical closure of one to 4 feet are aligned along the bases of scarps at Big Mountain North and at Cowan Gap. At Big Mountain South the basins are not aligned, but are partially connected by linear troughs, similar to a series of interconnected pools. Mounds of rubble protrude from a block field east of Township Run on the breached flank of Big Mountain anticline, 4,800 feet $S35^\circ E$ of the Big Mountain Fire Lookout. The mounds are teardrop shaped, rise 5 to 10 feet above the block field, and are asymmetrical downslope, like the rubble ridge shown in Figure 10. The rubble in the mounds has moved outward and downslope relative to the rest of the block field.

Just like screes, block fields in this area are commonly thought to originate by intensive frost wedging under a rigorous periglacial climate. The basins in the block fields also may be relics from a former more rigorous climate when they were either centers of patterned-ground polygons or places that contained ice lenses now destroyed by melting. The criterion for determining the time of origin of the screes applies also to the origin of block fields: before the block fields can be attributed to periglacial effects, it must first be proved that they were not produced by modern weathering. Although uprooting of trees may have produced the smaller depressions commonly noted in the regolith, no uprooted modern trees were observed to have produced basins half the size of the larger basins in the block fields. The basins at Big Mountain North and Cowan Gap are located along structural breaks that are also zones of water percolation.

Shale-chip rubble

Accumulations of shale chips mantle hillsides underlain by shale. The peg-like chips are about one-half inch long and less than one-quarter inch

in diameter. Their shape is due to breakage of shale bedrock along both cleavage and bedding planes. Where unweathered, most of the shale-chip rubble is well sorted and has little or no matrix. The fresh shale chips are gray and firm, but they weather to a punky, yellowish-brown soil and are not readily distinguished from normally weathered shale bedrock. Stratification, apparent only on fresh vertical exposures, is defined at intervals of about 6 inches by about one-inch bands of shale chips in a clay-rich matrix. Stratification parallels the surface. Orientation of the long axes of the chips is parallel to the surface slope. The shale-chip accumulations, commonly only a few feet thick, locally exceed 15 feet in thickness. Some of the thicker deposits are quarried for road metal.

All the exposures of shale-chip rubble noted overlie the Reedsville Formation in Path Valley near West Branch. The only good exposure observed in the quadrangle is in a cut on a private road on the east bank of West Branch (7,300 feet N13°E. of the intersection of State Highway 75 and the Cowan Gap Road). An abandoned meander of West Branch appears recently to have undercut the shale banks, oversteepening it to more than 30°. Exposures of similar rubble are present on gentle slopes near hillcrests in the Mifflintown quadrangle, 45 miles northeast of this area. (R. Conlin and D. Hoskins, personal communication).

The origin of accumulations of shale-chip rubble is problematical. These features might be solifluction deposits formed under a periglacial climate. However, it is not known whether the rubble is being formed at present. On the oversteepened slope at the locality along West Branch, shale chips could have accumulated in the same manner as do miniature talus cones built of shale chips on oversteepened slopes of local shale roadcuts. Shale-chip accumulations on slopes of 5° to 150° near the crests of shale hills in this and other areas indicates that an explanation by oversteepening is not applicable to all the accumulations.

*Rubble with a matrix and associated regolith
on moderate slopes of 5° to 20°*

Rubble with a matrix mantles the bedrock of intermediate and lower mountain slopes as well as gentle slopes near some of the mountain crests. Sharpstones in this rubble are generally smaller and more weathered than those in the screes and block fields. Most clasts are Tuscarora sandstone; the matrix consists of sand and finer material with admixed organic matter. Upon weathering, this rubble forms a rocky soil, usually classified by soil scientists as Dekalb or Lehigh soil material and Dekalb gravelly or stony fine sandy loam (Higbee and others, 1938). This soil supports growths of hardwood timber. The areal extent of such regolith is much greater than that of the screes and block fields, for it covers more than 70 percent of the mountainous area of the quadrangle. As revealed

in numerous roadcuts, debris of this kind is one to 20 feet thick and averages about 5 feet in thickness. Above shale bedrock, the sandstone rubble is concentrated in a surficial layer 2 feet thick, which overlies weathered shale debris that locally contains scattered fragments of Tuscarora sandstone.

Although no systematic measurements were made relating average size of debris at the surface to local topography, a few generalizations can be drawn from field observations reinforced by a detailed study in a nearby area. Field measurements by Hack and Goodlett (1960, p. 13-15) on the regolith at the surface of a mountainous area in the Appalachians of Virginia indicate a direct relationship between concentration of local runoff as determined by topography and mean grain size and sorting.* The amount of runoff crossing a given countour segment is a function of the drainage area supplying runoff to this segment. Hack and Goodlett found regolith on topographic noses to be poorly sorted and much finer than the well-sorted, coarser, angular debris in hollows.

Rubble with a matrix and associated regolith on moderate slopes can be divided into three gradational categories. (1) Rubble imbedded in a plentiful matrix mantles the greater part of the interfluves. Where only a small drainage area contributes runoff, the debris is least affected by winnowing action of the runoff because the fine-grained matrix is not vigorously eroded. As the drainage area contributing runoff increases, the grain size and sorting increase. (2) Rubble with a limited matrix occurs between the first-order-valley interfluves on the slopes above the hollows. Average grain size is larger because the rubble is scoured by sheet erosion and finer debris is removed. This rubble generally grades mountainward into screes. (3) Rubble with little or no matrix occurs in the hollows, where runoff is most highly concentrated. Within the hollows this material coarsens downslope and centrally toward the channel, until there is no matrix in the surface rubble on the channel bottoms.**

The matrix of the rubble is formed continuously by weathering of the sandstone and shale. The presence of fines at the surface depends upon the intensity of washing by runoff, especially during times of high-intensity precipitation (Hack and Goodlett, 1960, p. 49). Creep slowly moves the whole mass downslope; sheet erosion causes a sorting as it

* The area studied by Hack and Goodlett is underlain largely by interbedded shale and sandstone which tends to minimize the influence of individual lithologic units on the major features of the topography. Conversely, within the McConnellsburg quadrangle the resistance of the bedrock varies a great deal from the sandstones in the mountains to the shale and carbonate rocks in the valleys. Consequently in the McConnellsburg quadrangle there is an additional significant factor in the relation of local topography to mean grain size of the mountain regolith.

** Thick accumulations of this rubble are discussed under Rubble fans and Rubble valley fills.

selectively moves the fines downslope. Full understanding of erosion and slope development in the mountainous area depends upon knowledge of the kinds of mass-wasting involved and the present and past rates of movement. Unfortunately, not even the present rates are known.

Piles of rubble on valley bottoms

Rubble ridges

Rubble ridges lie on a few of the first-order-valley floors.* The surfaces of these elongate mounds, or ridges, are armored with large sandstone blocks; beneath this veneer sharpstone are packed in a matrix of yellowish-gray sand. The sharpstones are of Tuscarora and Juniata sandstone and the matrix appears to be mostly disaggregated Tuscarora sandstone. The ridges lie below very steep valley heads that slope more than 25°. The rubble ridges are 10 to 20 feet thick. Only two well-displayed rubble ridges were observed; the following discussion is restricted to them.

The best-displayed rubble ridge lies in a valley tributary to Township Run, 4,650 feet S35°E from Big Top Mountain Fire Lookout. Figure 10 shows a plan and two profile sections of the ridge and surrounding country. Maximum length, width, and thickness are 200, 50, and 15(?) feet. A few feet inward from the perimeter of the ridge the surface is flat with a down-valley slope of 6°. The frontal part slopes 14°. Although the line of intersection is now poorly defined, these two slopes appear to have a real intersection. Vague ridges and furrows, with amplitudes of the same size (1 to 3 feet) as the larger blocks, form an arcuate pattern, convex downslope. At its toe the ridge stands above the level of the almost-flat topography which is here an open valley; at its head the ridge funnels into a gully 25 feet deep. The surrounding surface is underlain by regolith consisting of rubble with a matrix of sand. With considerable effort, an 8-foot pit was dug into the frontal slope of the rubble ridge to determine the character of the interior of the rubble and its basal contact. The following debris was encountered:

Surface—Open rubble

- 0-7' Sharpstones, blocks with dimensions up to 8x5x5 feet of Tuscarora and Juniata sandstone with yellowish-gray quartz sand matrix. Smaller fragments lie between the larger blocks. Organic matter, including charcoal, has sifted down into the matrix of the rubble near the surface. Most sharpstones are in mutual contact. The base of the rubble ridge is probably at 7 feet. No ancient organic matter was noted.
- 7-8' Sandy zone, which becomes more gravelly with depth. Pebbles are sub-angular and appear slightly water worn. At bottom of the pit are more angular sharpstones up to 6 inches in diameter. The bottom of the pit is 1 to 4 feet below the surrounding surface not covered by the rubble ridge.

* First-order streams are "unbranched fingertip tributaries" (Horton, 1945, p. 281).

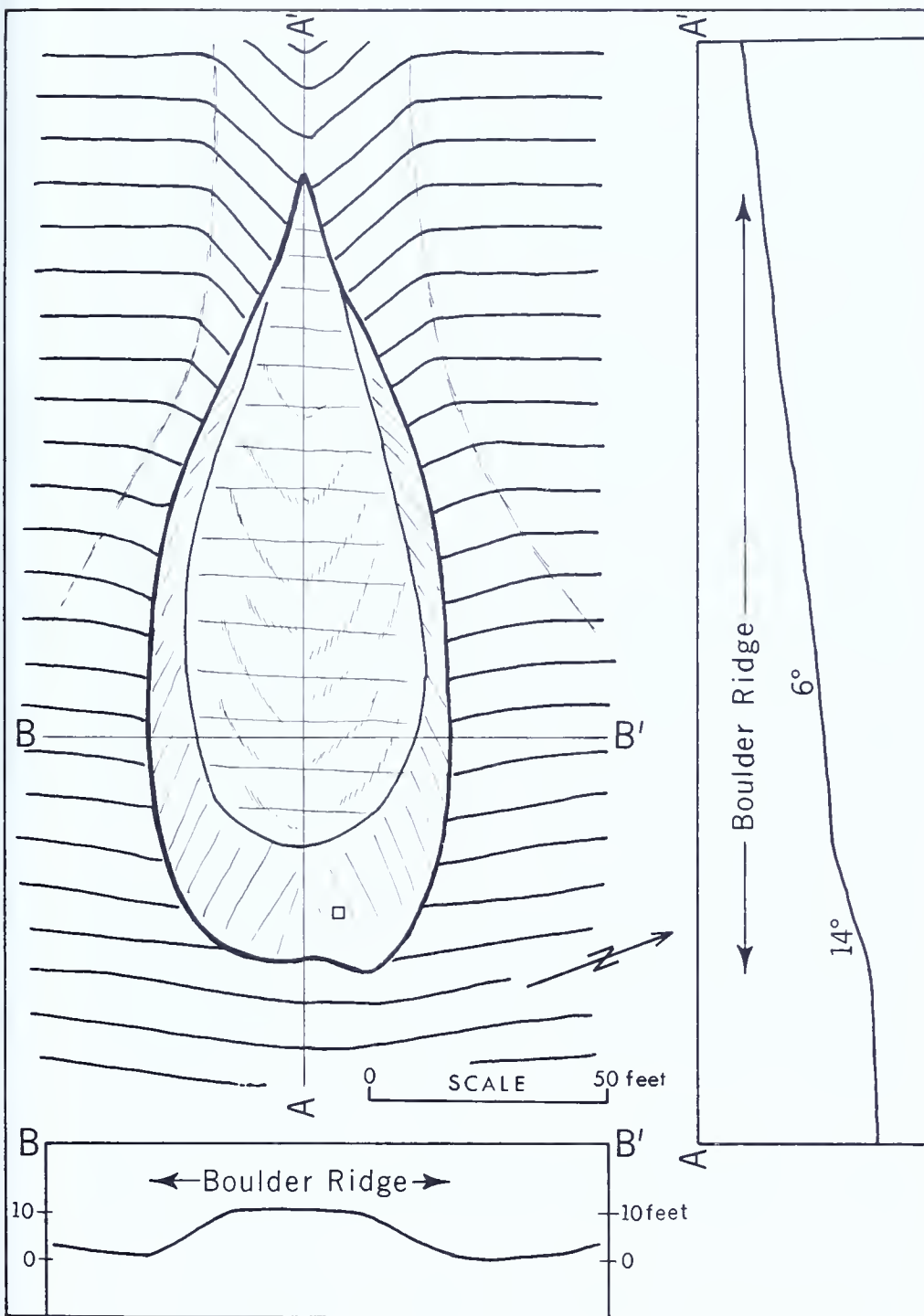


FIGURE 10. Rubble ridge near Township Run, perspective sketch and profile section
Location of pit indicated by square.

A much longer rubble ridge extends from West Branch (7,800 feet north of Fort Loudon) up a tributary valley on the side of Kittatinny Mountain through a distance of more than half a mile, where it appears to merge upward into a scree. The slope gradually increases from 7° on the lower part to 25° in the cirque-like valley head. Near the West Branch the ridge is well defined and stands 15 feet above the surrounding country. In the middle section the ridge is poorly defined, and in most places now has only one side, which slopes down to the present stream. A longitudinal profile along the gently sloping lower part of the rubble ridge shows two 5-foot step-downs; the frontal parts of the step-downs slope 15° .

The origin and age of the rubble ridges are uncertain. The topographic freshness of the ridge suggests a recent age. Decayed oaks rooted in their surface indicate an age of at least a few hundred years. Their form and occurrence suggests that the ridges were emplaced by mass movement as discrete bodies.* Rubble ridges may be the result of debris slides or avalanches, but if so they do not display the forms characteristic of such features. An alternative hypothesis is that the rubble moved downslope by flow within an ice matrix similar to the mechanism described by Wahrhaftig and Cox (1959, p. 433) for Alaskan rock glaciers. This mechanism might be applied also to the rubble mounds noted on some of the block fields as described earlier. However, this hypothesis is apparently ruled out by the empirical observation that a minimum thickness of about 100 feet of rock and ice is required for active movement of rock glaciers (Wahrhaftig and Cox, 1959, Table 9).

Debris slides and avalanches

Lobate accumulations of rubble occur at the bases of some very steep (25° to 30°), first-order valley heads. The sharpstones are from Tuscarora and Juniata sandstone. At the surface of some accumulations the blocks average more than one foot in diameter. Some deposits have a matrix; others are open to a depth of at least 5 feet. The accumulations are elongate downvalley, and measure a few hundred feet long, 50 to 100 feet wide, and probably 10 to 50 feet thick. Their surfaces are not flat, but bulge downslope with a teardrop form. Poorly defined mounds and depressions form a surface pattern that is convex downslope. The accumulations lie at a marked decrease in slope, generally at the sand-

* It would be possible to form a rubble ridge by stream erosion of less-resistant material on both sides of a rubble-filled V-shaped valley, and thus produce a local reversal in topography and a W-shaped valley. Although this is a possible explanation for rubble piles in W-shaped valleys, it does not account for the situation developed at the toes of the two ridges described; the toe of the ridge rises above a nearly flat topography also mantled by rubble.

stone-shale contact. On the east flank of Cove Mountain along the Mercersburg reentrant, mounds of rubble occur in almost every first-order valley.

Probably debris avalanches (water- or snow-rich flows) or debris slides (block movement above slip surfaces) are responsible for these accumulations. The deposits are similar to those noted in Virginia by Hack and Goodlett, except that the chutes down which the debris moved are not recognizable in the McConnellsburg quadrangle. According to Hack and Goodlett, (1960, p. 44), this type of slide occurs characteristically in humid climates and is accompanied or preceded by heavy rains.

Rubble fans and rubble valley fills

Conical piles of rubble have accumulated where low-order, high-gradient streams enter larger, much lower-gradient streams. Rubble which, except for topographic shape, is similar in character and origin to rubble fans, lies on the bottoms of most of the mountain valleys. The rubble fans and valley fills consist of rubble in a sandy matrix. Many fragments of Tuscarora and Juniata sandstone are partly rounded. The radii of some rubble fans, measured from apex to perimeter, are greater than one-quarter mile, but more commonly they are only a few hundred feet. Radial slopes range from 5° to 15° and are concave upward. The rubble fans and valley fills are locally 30 feet or more thick. Where partially eroded they form discontinuous fill terraces. Usually the peripheries of the rubble fans are undercut by the main streams. Well-developed debris fans occur at the mouth of first-order valleys entering Buck Run from the east slope of Tuscarora Mountain.

The debris in rubble fans and valley fills is the result of mass movements as well as selective stream deposition and erosion. Hack and Goodlett (1960, p. 53) described debris fans deposited by floods caused by exceptionally great, high-intensity precipitation. Rubble is introduced by streams and sheet erosion during times of floods. Fines are introduced by stream deposition, and weathering of coarser material in place. The rubble is removed by weathering in place and by undercutting by the main streams. The fines are removed by the tributary and main streams either selectively or along with the rubble. Slight rounding of many of the clasts in the rubble fans and valley fills indicates their gradational relation to the deposits of rounded sediments discussed in the next section. Rubble fans and valley fills appear to be both receiving and losing material at the present time.

Conclusions on Angular Regolith

The mountain regolith has been described mainly in terms of the rubble, the sharpstones of which are derived dominantly from the Tusca-

rora Formation. Thus, besides holding up ridge crests, resistant Tuscarora sandstone also mantles mountain slopes, where it also greatly inhibits erosion of the underlying rocks. As demonstrated by Hack and Goodlett (1960), high-intensity storms of rare frequency are important in the total erosion of the central Appalachians; such storms are necessary to move large blocks of Tuscarora sandstone out of the smaller valleys. Most of the topography seems to be in a state of "dynamic equilibrium" (Hack, 1960) or steady-state erosion, and, as discussed further in the last section, appears to be adjusted in each place to the erodibility of the regolith and bedrock.

The origin of the screes, block fields, accumulations of shale-chip rubble, and rubble ridges may be a consequence of a former, more rigorous, periglacial climate. Nevertheless modern winters still have alternating periods of thaw and intense freezing, which must produce geologically significant frost wedging. More information on rates of modern processes must be acquired before the role of periglacial action can be fully appraised.

ALLUVIUM

Along and above the streams are accumulations of modern, or relatively unweathered, alluvium (gravel, sand, mud) and nonsorted deeply weathered(?) roundstone diamicton (Pl. 3). Sediments of alluvial origin lie in depressions that range from the smallest swales to the largest valleys; only the larger accumulations are discussed here. Soil scientists have mapped and described the relatively small, locally derived accumulations of alluvium and colluvium in the swales (Higbee and others, 1938; reports on file, Soil Conservation Service, McConnellsburg, Pa.).

Modern Alluvium

Along the larger streams, undercut banks expose alluvial beds of moderately-sorted to well-sorted, stratified mud, sand and gravel. Similar sediments are assumed to underlie the low flat surfaces along the streams (Pl. 3). Light-brown silt deposited on flood plains constitutes most of the alluvium. Less common lenses of sand and gravel represent stream-channel deposits.

Descriptions of alluvium along some streams and some eventful stratigraphic sections are presented to give an idea of the variable character of the alluvium and the possible history it may record.

Cove Creek

Near McConnellsburg, Cove Creek flows on carbonate residuum a few tens of feet thick. Minor tributaries from the lateral sandstone ridges flow to Cove Creek, but none of these are competent to transport readily

sandstone clasts larger than 4 inches through the one or two miles to Cove Creek. Bank exposures display beds of silt 1 to 4 feet thick with minor lenses of brownish-gray sand and gravel, all generally overlying clayey, carbonate residium. The gravel is well rounded to subangular, and composed mostly of Tuscarora sandstone. The matrix of the gravel is sandy, commonly with abundant chips of shale. Some alluvium within two feet of the surface yields artifacts less than 200 years old. In these places, local channel cutting to a depth of 5 feet has occurred since the deposition of the artifacts.

West Branch

West Branch is the largest stream in the quadrangle. Some segments flow on coarse gravel, some on bedrock, and some on silt. Along the floodplain between Fort Loudon and Richmond Furnace, chutes 10 to 20 feet wide are cut into the floodplain, which is otherwise covered with luxuriant vegetation. The chutes parallel the main stream, and locally remain hundreds of feet away from it for distances of one mile.

Four different late Cenozoic materials are exposed in a vertical section along the bank of West Branch, 3,100 feet N20°E of the intersection in Richmond Furnace of the Cowan Gap road and State Highway 75 (10,050 feet S of lat. 40°00' and 5,500 feet E of long. 77°55'):

Depth in feet

Top	Forest
0 to 3	Diamicton. Roundstones of sandstone in a matrix of sandy clay and weathered chips of shale. Shale weathers yellow, clay is light reddish brown. Roundstones are subangular.
3 to 4.5	Clay, sandy and silty, light-gray with the dark yellowish-orange mottling, becoming lighter toward the base. More than 40 percent sand and silt. A paleosol
4.5 to 5.5	Interlayered light and dark-gray clay, the latter rich in organic matter. Weathers into irregular one-inch blocks.
5.5 to 8	Clay, sandy, light-gray. Breaks into 6-inch blocks. Becomes more sandy at base. Some finely divided organic matter.
8 to 8.5	Gravel, sandy, medium-gray. Pebbles and cobbles of sandstone with a few slightly weathered pebbles of shale. Clayey sand matrix is in a reduced state.
8.5	Bedrock, fresh shale. Local sub-horizontal planation surface.
9	Level of West Branch. Bottom of the stream channel is fresh shale overlain by scattered sandstone roundstones.

This section indicates the following sequences of events: (1) planation to fresh bedrock by West Branch, (2) deposition of gravel, (3) ponding of water (a lake?) and deposition of silty clay in a reducing environment with abundant organic material, (4) subaerial weathering? forming a paleosol, and (5) deposition of the material now represented by the diamicton.

Near the Mt. Parnell Fish Hatcheries, well downstream from the localities just described and more than two miles from the nearest sandstone outcrops, many stretches of West Branch are still bottomed by coarse sandstone gravel that is moved only during times of high water. The low plain which extends a few thousand feet northeast of the Fish Hatchery is underlain by light-brown clayey silt. Very few roundstones occur on this plain.

Northeast of this plain along a tributary draining Parnell Knob (6,850 feet S55°E of Fort Loudon or 4,800 feet S of lat. 39°55' and 8,750 feet E of long. 77°55'), the following creek-bank section is exposed, containing organic material and artifacts:

Depths in inches

0 to 4	Loam, sandy with grass roots.
4 to 14	Loam pebbly, light-brown. Pottery of white man.
14 to 24	Sand, pebbly, reddish-brown.
24 to 30	Clay, sandy, gray. Abundant organic matter, especially near the top.

Buck Run

Buck Run originates in a narrow axial valley and flows south between rubble-mantled sandstone ridges to Cove Gap, where it turns east, cuts through Cove Mountain, and flows into the Mercersburg reentrant. Because Buck Run and its tributaries flow along the bases of steep slopes mantled by sandstone rubble, Buck Run carries coarse rubble or gravel even in the Mercersburg reentrant a few miles from the mountain. In Cove Gap rounded boulders as large as 4 by 4 by 2 feet are imbedded in the channel. For the next mile the channel is above carbonate rocks and is normally dry, but here during times of high runoff Buck Run has moved boulders more than one foot in diameter and washed out heavy stone culverts.

One mile northwest of Dickey (250 feet N of lat. 39°52'30" and 1,350 feet E of long. 77°55') channel and creek bank exposures reveal some interesting features concerning the original and weathered character of gravel. Well-rounded, imbricated roundstones pave the stream channel; these roundstones are moved only during floods. A matrix of sand with some silt and clay lies between these roundstones. It is virtually impossible to deposit silt and clay and to move roundstones in the same current. The silt-clay fraction of the matrix apparently was deposited between the roundstones at times or in places of slow currents. Chips of shale also occur in the fresh matrix. A bank exposure four feet high displays the following section of alluvium:

Depth in feet

Top	Grass on surface
0 to 0.1	Organic soil
0.1 to 1	Gravel or diamicton, medium-gray, imbricated. Matrix has considerable clay. Chips of shale in matrix are deeply weathered. Clay has been introduced between the clasts: the B-horizon of the modern soil.
1 to 2	Silt, sandy, light-brown.
2 to 4	Gravel, brownish-gray, loose sandy matrix, imbricated. Some open cavities. Except for minor clay coating on the pebbles, this part shows little effect of weathering.

Campbell Run

East of the quadrangle, at the south end of an amusement park (2,950 feet S50°W of Saint Thomas, or 1,600 feet S of lat. 30°55' and 7,550 feet E of long. 77°55') the bank of Campbell Run presents a silt and gravel section:

Depth in feet

Top	Overgrown farmland.
0 to 0.5	Organic soil.
0.5 to 3.5	Loam, some chips of shale, light brownish-gray compact.
3.5 to 7	Clay, silty, light-gray, mottled.
7 to 8.5	Clay, silty, light-gray.
8.5 to 8.8	Clay, gray, with organic material.
8.8 to 10.4	Roundstones in sandy, silty-clay matrix, light-gray. Roundstones up to 4 inches in diameter. Some fresh shale bedrock exposed in stream.

Conococheague Creek

Across the Cumberland Valley twenty miles east of the quadrangle, the main branch of the Conococheague Creek flows westward from the Lower Cambrian rocks of South Mountain onto the Cambrian and Ordovician carbonate terrain of the Cumberland or Great Valley. Where Conococheague Creek enters the Cumberland Valley, excavations at the Mount Cydonia Sand Company Quarry No. 2 expose a pebble and cobble gravel with a sand matrix. The thickness of the gravel ranges from 8 to 20 feet between a planar upper surface and an irregular lower contact with poorly sorted, clayey, carbonate residuum. This basal contact is irregular and locally slopes 20°. The upper surface of the alluvium stands only a few feet above Conococheague Creek. The main body of alluvium is well-sorted, medim-gray to dark-yellowish-orange gravel with imbricate structure. The matrix is unconsolidated and sandy, with little silt or clay. Roundstones are about 75 percent well-rounded quartzite and 25 percent metamorphosed Catoctin volcanic rocks. A distinctive dusky-blue, well-indurated quartzite from the Mont Alto or Antietam

Formation is common in this and other alluvial deposits along Conococheague Creek. Roundstones of iron ore are also present. Little weathering of the gravel or its matrix has occurred. The metavolcanic roundstones display polished surfaces and commonly fresh crystalline interiors.

Cemented zones and grain coatings of iron and manganese oxide occur along a subsurface channel tributary to the main stream. A lens 50 feet wide and one to 2 feet thick of dark-gray gravel cemented by manganese oxide overlies another lens of similar dimensions of dark-yellowish-orange gravel coated by iron oxide. The color contacts between the iron and manganese zones and between these zones and the surrounding gravel are remarkably sharp.

Roundstone Diamicton

The term diamicton was introduced by Flint and others (1960) as a nongenetic name for nonlithified, essentially nonsorted, terrigenous deposits composed of sand and (or) larger particles in a muddy matrix. In the McConnellsburg quadrangle and the area adjoining it on the south, six diamicton fans and several other diamicton bodies (Pl. 3 and Fig. 11) were recognized and studied. The diamicton in these deposits contains rounded clasts; hence the expression roundstone diamicton. Roundstone diamicton is of importance not only in this area but regionally as well,

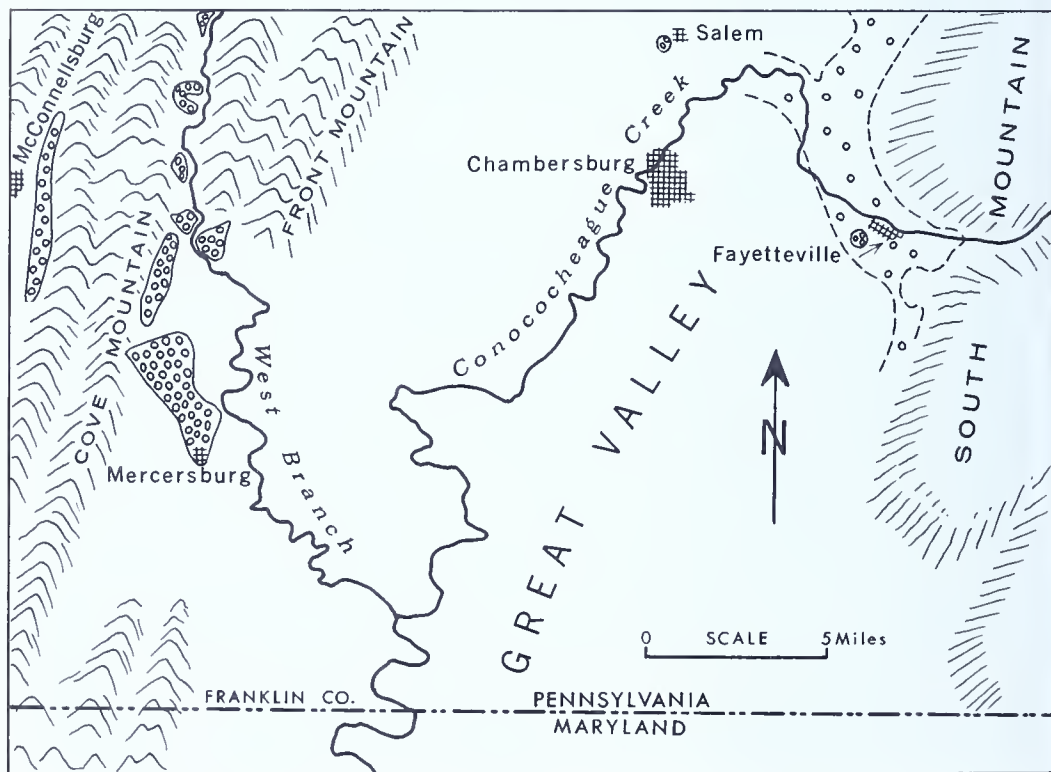


FIGURE 11. Location of diamicton deposits studied, south-central Pennsylvania.

for similar deposits appear to be widespread throughout the central Appalachians.

Valleyward from the bases of the mountains, the diamicton is characterized by roundstones in a bright-colored matrix. The following section deals mainly with this more distinctive facies of diamicton. On the mountain sides, the diamicton consists of sub-angular fragments in a clayey sandy matrix, gradational with the "rubble with a matrix" described earlier in this report; this mountain-side regolith would not impress most geologists as unusual and would be simply considered as float or wash.

Previous work

The diamicton of this report was mapped and described by Stose (1909, map legend) as coarse sand and gravel on stream terraces and elevated alluvial fans. He (p. 17) postulated that this ancient gravel was deposited on the Harrisburg erosion surface. Most other geologists have also considered these deposits to be terrace gravels. Similar deposits in Virginia and Tennessee were mapped and described by King (1950, p. 57-62), and King and Ferguson (1960, p. 92).

The diamicton in outcrop

Throughout almost its whole areal extent the diamicton is recognizable only by rounded clasts of sandstone at the surface of a clayey soil. Natural exposures do not show the vertical dimension and only in artificial cuts with nearly vertical faces is it manifest that the roundstones are "floating" in a fine-grained matrix (Fig. 12 and 13). The roundstones occupy less than half the area of a fresh face. On a weathered exposure, however, a "gravel" or a lag of roundstones masks the deposit.

The sandstone clasts come from sources in the nearby mountains. Well-indurated rocks relatively insoluble in normal weathering constitute most of the roundstones. They are light-gray orthoquartzite from the Tuscarora Formation, red sandstone from the Juniata Formation, and "iron" sandstone from beds in the Rose Hill Formation. Less than 25 percent of the roundstones are derived from impure sandstone, siltstone, and shale of the Bald Eagle Formation, the Reedsville Formation, and the Rose Hill Formation, even though these formations together have a much larger outcrop area than the "iron" sandstone and Tuscarora and Juniata sandstones.

The roundstones are generally sub-angular to sub-rounded near the mountains, and are moderately well-rounded to rounded a mile or so from the mountains. Imbrication of the discoid roundstones is not readily apparent in outcrop, but is present as determined by fabric measurements.

In many localities some roundstones are weathered but still retain their identity in the faces of exposures. No gradation could be seen between deeply weathered roundstones and the surrounding clayey matrix, even around the boundaries of shale roundstones. If limestone clasts were originally present, they have been completely leached, leaving residual clays behind.

On casual inspection the matrix appears to be entirely clay, but close examination reveals much silt and sand coated with a clay "paint." The color of an exposure, moderate reddish brown to dark yellowish orange, is due to this surface coating of clay. The color of the clays in the diamicton is brighter (either redder or more ochreous) than the colors observed in the normal soil profiles formed from noncarbonate rocks.

Just west of Fort Loudon, the U.S. 30 Bypass cuts through an interesting section of the Rocky Hollow diamicton fan and other surficial materials. Although the cut is grassed over, it was possible by digging



FIGURE 12. Lens of roundstone diamicton underlying and overlying Beekmontown residuum. Buck Run diamicton, Mercersburg, Pennsylvania. Apparently this diamicton is a cove deposit.

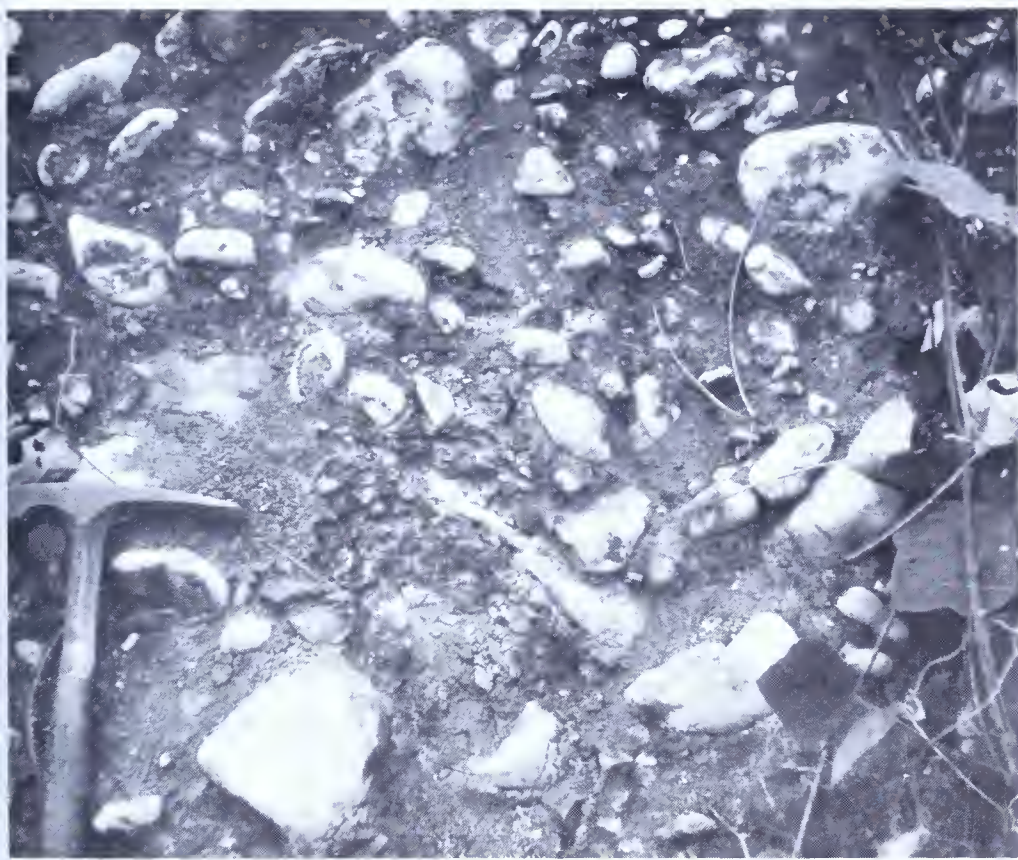


FIGURE 13. Roundstone diamicton, Shenandooh Valley, Virginia. Consists of quartzite cobbles in a clayey matrix.

into the banks to get an idea of the surficial materials present and their relations to each other. In the bottom of Rocky Hollow, 60 feet below the top of the road cut, Saint Paul Limestone and Bellefonte Dolostone crop out. At the top of the cut is a surface capping of roundstone diamicton about 10 feet thick. Below this is about 20 feet of silty clay, quartzose sand, and diamicton. The sand is in lenses several inches thick, which are deeply weathered and impregnated with iron oxide and secondary clays. In the upper 30 feet of the exposure, zones of clays are probably of residual or residual-colluvial origin, but alluvial clays may also be present. The lower 30 feet of surficial materials is largely residual clay containing scattered sandstone clasts that were perhaps introduced into caverns and open joints before formation of the carbonate residuum.

A temporary exposure of an apparently special type of roundstone diamicton occurred in the northwest part of Mercersburg behind the Fox Motors building. There a two-foot bed of reddish roundstone diamicton is underlain and *overlain* by dark-yellowish-orange, poorly sorted, laminated clay (Fig. 12) containing quartz crystals and gray chert fragments. The laminated clay appears to be Beekmantown residuum. The diamicton bed thins to only a few inches through a distance of 10 feet up

an apparent dip of 15 degrees. The clasts in the diamicton could be derived only from the sandstone mountains; the closest and most probable source is near Cove Gap, 2.5 miles west. Apparently the diamicton bed was deposited in a cave by an underground stream. Subsequently the enveloping carbonate rocks have weathered to residuum. At this locality, the several feet of diamicton at the land surface may be either the remnants of other cave deposits, or a roundstone deposit originally laid down on the surface.

Other exposures in the Cumberland Valley—A most informative exposure of diamicton occurs on the east side of the Cumberland Valley in an excavation near U. S. Highway 30 Bypass, 4500 feet due west of Fayetteville. As shown in Figure 14, 5 to 10 feet of roundstone diamicton lies with irregular contact on light-brown, silty-clay residuum. The diamicton is similar both in texture and in the presence of a bright-colored clayey matrix to that in the McConnellsburg quadrangle. Presumably the roundstones were derived from the Cambrian quartzites of South Mountain: a light-brown, massive, slightly foliated quartzite and a distinctive highly indurated, dusky-blue quartzite. A lens, one-foot thick, of well-sorted alluvial sand showing cut-and-fill stratification occurs near the base of the diamicton (Fig. 14). This exposure is part of a continuous sheet of roundstone diamicton that extends along the banks of Conococheague Creek (Stose, 1909, Chambersburg quadrangle). As described earlier, Conococheague Creek is now transporting roundstones of Catoctin volcanic rocks. No roundstones of Catoctin volcanic rocks are now reconizable in the diamicton. The absence of Catoctin volcanic rocks from the diamicton might be accounted for by assuming that the quartzite roundstones were transported into the Cumberland Valley by a nearby stream that drains an area to the southeast devoid of outcrops of volcanic rocks. However, many other surficial exposures of roundstone diamicton occur along the valley of the Conococheague between this excavation and Scotland, Pa.; none of them contains Catoctin volcanic rocks but all contain the dusky-blue quartzite.

For example, above Conococheague Creek in excavations for the city dump south of Chambersburg, clay-rich roundstone diamicton a few feet thick overlies deeply weathered Martinsburg shale. The roundstones are light-brown and dusky-blue quartzite similar to those near Fayetteville. Similarly colored quartzite roundstones also occur a few hundred feet northwest of Salem (Fig. 11). These roundstones near Salem are now present only above carbonate bedrock; they are not found above the shale bedrock on the same hill. The dusky-blue quartzite came from the South Mountain area about 10 miles east; the nearest modern stream carrying this quartzite is Conococheague Creek, 1½ miles southeast.

In conclusion, the absence of volcanic rocks from the diamicton along Conococheague Creek is believed to indicate that the Catoctin volcanic



B. Lens of well-sorted alluvial sand in diamicton.



A. Diamicton overlying carbonate residuum.

FIGURE 14. Roundstone diamicton at Fayetteville, Pennsylvania. Exposure located above Conococheague Creek along U. S. 30 Bypass, 4,500 feet west of Fayetteville.

rocks that apparently were deposited in these sediments were destroyed subsequently by weathering.

Distribution of the diamicton

Extensive sheets of roundstone diamicton occur along the northwest side of the Cumberland Valley, downslope from a marked change in slope on the north and west sides of the Mercersburg reentrant and on the west side of Path Valley (Pl. 3). The deposits generally lie at or slightly above the topographic position of the Harrisburg surface. In this report, the fan-shaped deposits are named Stumpy Run, Pump Run, Township Run, Rocky Hollow, Broad Run, and Buck Run diamictons (Pl. 3). These fans occur downstream from the confined upper reaches of streams of the same names, and their apices are at the points where the streams' debouch into the open valley. Altitudes of the diamicton fans range from 600 to 1,000 feet above sea level, or 10 to 400 feet above West Branch, the main axial stream.

Many diamicton accumulations occur along smaller streams in poorly exposed patches (Pl. 3). Some appear to be linear and only a few tens of feet wide, like the channel filled with diamicton on the side of Tuscarora Mountain 500 feet above the valley floor (Fig. 16A). Others are much more extensive, like the band of hummocky diamicton, half a mile wide, that passes through Dutchtown, on the east flank of Cove Mountain about 200 feet above West Branch.

In the southeastern part of the McConnellsburg quadrangle, diamicton mantles benches 60 feet above the river and occurs in meandering patches at lower altitudes. A little farther east near Markes and Lemasters, a "gravel" mapped by Stose (1909) along West Branch is represented in some places by scattered roundstones, but in other places roundstones are absent.

In Path Valley and in the Mercersburg reentrant, scattered roundstones in a residual regolith are present on most of the low hills of shale and carbonate rocks within a few miles of the mountains. The slope between these occurrences and their mountain sources is in places reversed indicating that locally as much as 100 feet of erosion has taken place since deposition of the roundstones. Evidently there is a gradation between the roundstone diamictons and the isolated roundstones in a residual regolith. The latter represents a lag concentrated by the weathering and removal of the less resistant roundstones and their original matrix.

Form and size of the diamicton accumulations

The thickness of the roundstone diamictons ranges from a feather edge to possibly more than 40 feet. A projected thickness of about 20 feet was measured in Mercersburg. A thickness of 100 feet of diamicton and un-

derling limestone residuum was encountered in a well drilled at The Inn in Fort Loudon. However, no well-exposed section of continuous diamicton more than 10 feet thick was noted. The lack of data from such high exposures is considered an important deficiency in this study.

The areas of the diamicton fans along the larger streams average about one square mile. The Stumpy Run and Rocky Hollow fans are one-half square mile in area; Buck Run is three square miles.

The slopes of the upper surfaces of the fans range from 0.75° to 8° . Slope increases toward the apex, but correlation of angle of slope on a given part of one fan with a similar part of another fan is not possible. For example, the slope at the head of the Buck Run fan is 1.5° whereas the slope at the head of the Rocky Hollow fan is 7° . The slope at the periphery of the Buck Run fan is 0.75° whereas the slope at the periphery of the Rocky Hollow fan is around 5° . Other patches of roundstone diamicton are too irregular in area and slope to be described with profit.

Two surfaces can be distinguished on the Rocky Hollow fan—a lower and younger (?) one on which the town of Ft. Loudon is built, and one about 50 feet higher northwest of Ft. Loudon. Elsewhere in the quadrangle, different fan levels are not apparent. In the Elkton area of Virginia, three different surfaces of gravel, or diamicton, are mapped by King (1950, Pl. 1).

Normally the surfaces of the diamictons are not planar. Depressions and ridges are present locally, paralleling the strike of the underlying bedrock. Upslope from some ridges are closed depressions in the diamicton, such as the deep pits west of Dutchtown. These depressions range from 50 to 200 feet in diameter and are as much as 30 feet deep. The depressions are underlain by carbonate bedrock and are sinks that owe their present relief to solution of bedrock after diamicton was deposited. Ridges in the diamictons on the mountain flanks stand 5 to 30 feet above adjacent terrain. An abandoned railroad cut, 30 feet deep, in one of these ridges west of Fort Loudon expose a thick section of diamicton, possibly with considerable admixed carbonate residuum. The ridges and sinks overlie either interbedded limestone and dolostone or pure and argillaceous limestone; they are the consequence of differential subterranean solution of the underlying carbonate rocks (Fig. 15).

The topography represented on the $7\frac{1}{2}'$ quadrangle maps shows the fans now standing above the surrounding terrain. Contour lines on the surface of the fans are convex downslope, and the axial streams appear to be deflected around the peripheries of the fans. This form may be due either to accumulation of diamicton above the adjacent terrain or to retardation of erosion by the diamicton subsequent to its deposition.

The diamictons are commonly dissected; in places erosion has cut 60 feet below the top of a diamicton, exposing underlying bedrock or re-

siduum. In each area the main stream, along some part of its course, has generally cut through the diamicton fan. Smaller streams that head on the fans have grooved and in some places have cut through the diamictons.

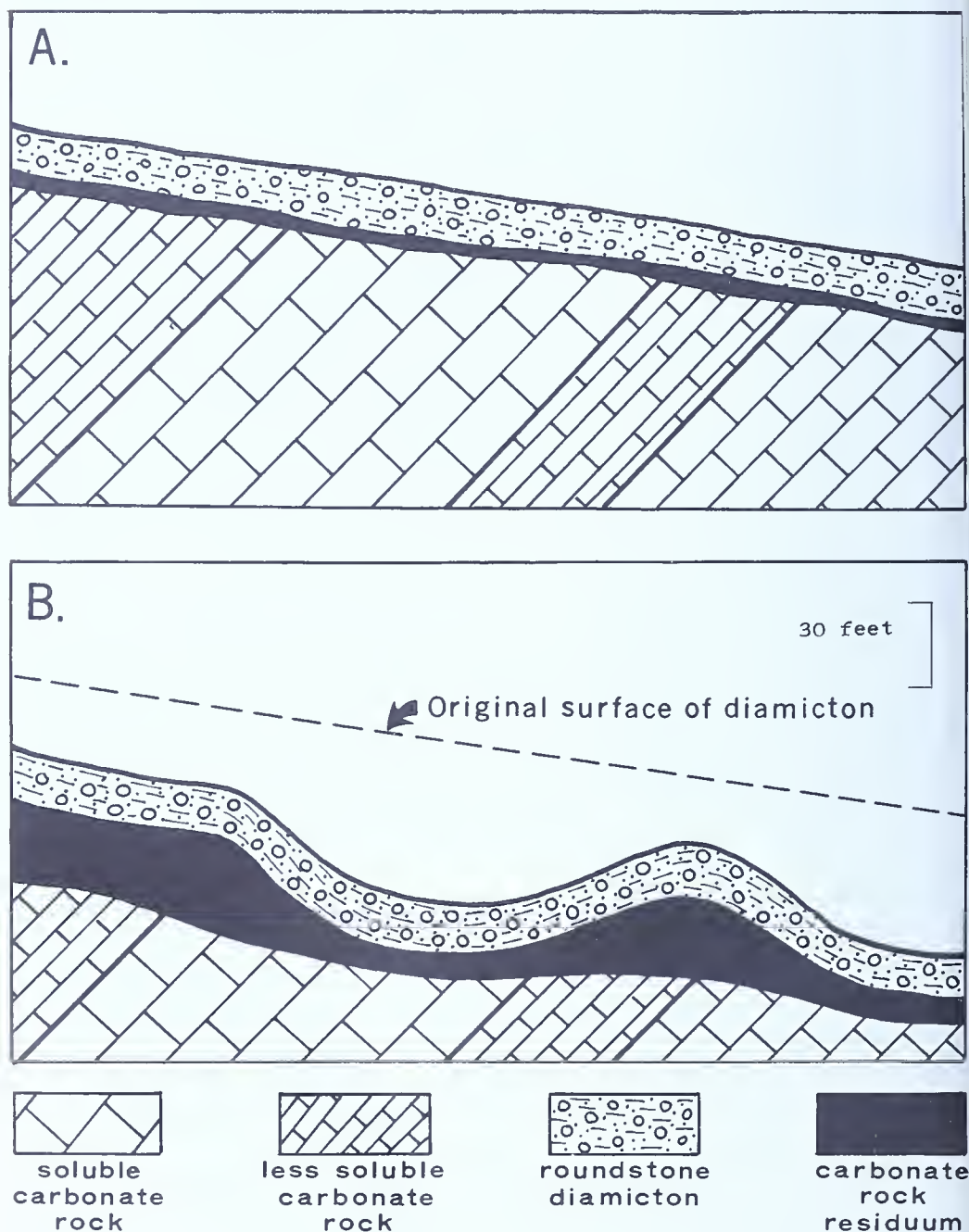


FIGURE 15. Formation of bedrock ridges beneath cover of roundstone diamicton. (A) Topography after deposition of diamicton and before post-diamicton differential solution of underlying rocks. (B) Topography after differential subterranean solution of soluble and less soluble carbonate rocks, showing development of a ridge 30 feet high over less soluble beds beneath roundstone diamicton.

Relation to the underlying bedrock

Exposures of the contact between diamictos and underlying bedrock are rare; consequently data on the contacts are limited to a few localities.

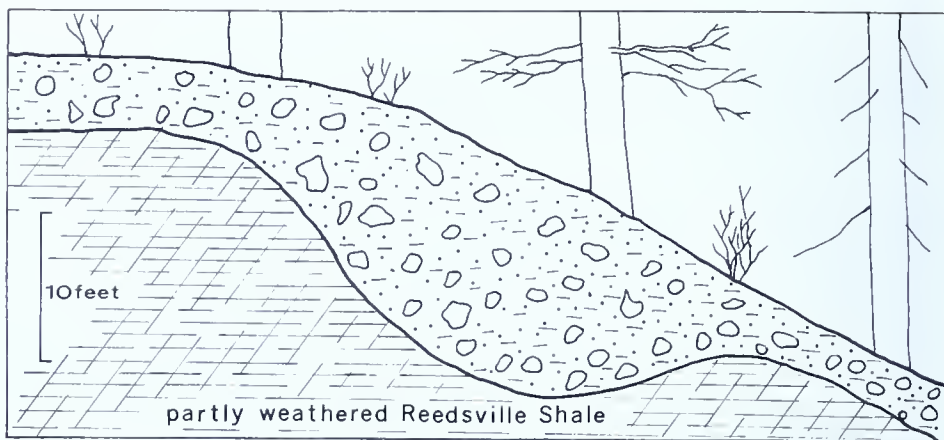
Part of the base of the Pump Run diamicton was exposed during the reconstruction of State Highway 75 in a road cut half a mile north of Richmond Furnace (Fig. 16B). Here the contact between a thick section of diamicton and the underlying Reedsville shale is gradational through a 6-inch clayey zone. At a depth of only 5 to 10 feet below the contact, the Reedsville shale is dark gray and only slightly weathered. The relief on the contact has slopes of as much as 40°. Farther west the diamicton and associated sandstone rubble (Pl. 3) are only about 5 feet thick and mantle a nearly planar surface cut on shale, possibly a pediment.

In the Rocky Hollow diamicton, contact between diamicton and underlying bedrock is exposed in the creek bottom at the apex of the deposit. As in the previous example, a thick section of diamicton unconformably overlies nearly fresh Reedsville shale.

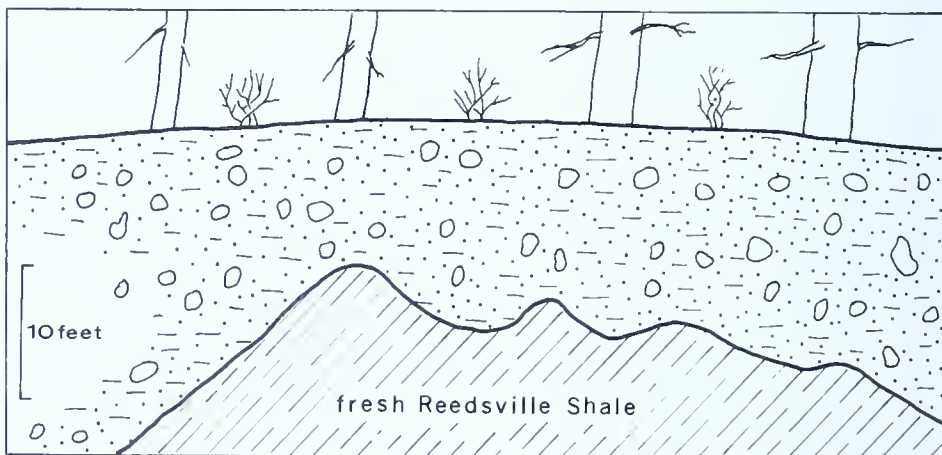
Along the U. S. 30 Bypass just south of the Fort Loudon Cemetery, deeply weathered diamicton a few feet thick overlies brightly colored, deeply weathered Reedsville shale (Fig. 16C). The shale surface here appears to be planar and may represent a pediment. Weathering of the shale may have taken place before emplacement of the diamicton. However, it is more likely that most of the weathering occurred afterward, while the shale was protected from surface erosion, though not from chemical weathering, by an armor of roundstones.

As carbonate residuum apparently everywhere intervenes between diamicton and carbonate bedrock, no contact between diamicton and underlying carbonate rocks was observed. The contact between diamicton and residuum was not well exposed in the area studied. Apparently it is neither planar nor very sharp. The underlying residuum is moderate reddish-brown, poorly sorted clay. Diamicton appears to have slumped and been deformed as the underlying carbonate rocks were dissolved away and more residuum formed. Thus the contact between diamicton and carbonate residuum is quite irregular and may even be folded into overturned folds as it is elsewhere in the Appalachians (King and Ferguson, 1960, Pl. 13).

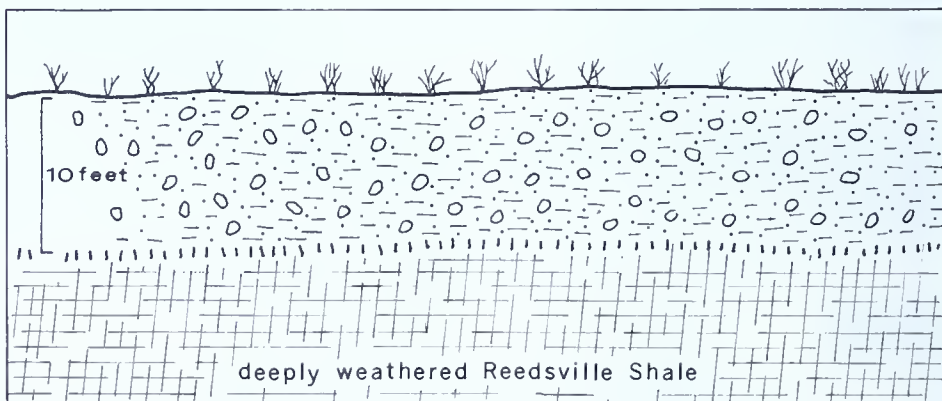
Locally caverns in carbonate bedrock beneath the diamictos serve as conduits for the transport of roundstones. For example, Reese Cave beneath the Dutchtown diamicton blanket is almost filled with sandstone debris introduced into the cavern by caving of the overlying diamicton; this sandstone debris weathers and is transported valleyward by streams within the cavern.



A. Channel in Reedsville shale filled with roundstone diamicton. Exposed in quarry along State Highway 16, 2 miles southeast of McConnellsburg.



B. Pump Run diamicton overlying rugged topography on fresh Reedsville shale.



C. Broad Run diamicton overlying level topography (pediment?) on now deeply weathered Reedsville shale. Exposed on U. S. 30 Bypass near Fort Loudon Cemetery.

FIGURE 16. Diamicton overlying shale.

Mechanical analyses

Seven samples were disaggregated and sieved in the field through 128-, 64-, 32-, 16-, and 8-mm sieves. Each sample weighed approximately 100 lbs. Each size fraction, including that less than 8 mm, was weighed in the field. A representative sample of the size fraction less than 8 mm was taken for laboratory analysis. Figure 17 shows the results of the mechanical analyses grouped into gravel (greater than 2 mm), sand (2 mm to $\frac{1}{16}$ mm), and silt-clay (less than $\frac{1}{16}$ mm). The diamicton is nearly equally distributed by weight among the above size limits.

The distribution of grain sizes that requires the coarser fragments of a sediment to be dispersed from each other is relevant to an understanding of the origin of the diamicton. A mass of unsorted gravel has a porosity less than 35 percent. If the pore space is now filled with unsorted sand that also has a porosity less than 35 percent, the total porosity of the sand and gravel mixture is less than 12 percent. If this remaining pore space is in turn filled with more than 12 percent silt-clay, the clasts of sand and gravel must be mutually displaced away from each other, or dispersed. The clasts would be even more dispersed in a water-rich sediment of this sort. Movement of a watery mass of gravel, sand, and silt-clay could be accomplished by flow within the silt-clay-water fraction. The coarser clasts would be carried along passively, bouyed up by the dense silt-clay slurry and suspended by turbulence as the mass flowed downslope.

All the mechanical analyses of normal diamicton show at least 13 percent silt-clay, and all of the five samples that were collected from more than 6 feet below the natural surface contained at least 20 percent silt-clay. Thus the size distribution indicates that the coarser fragments are dispersed.

Samples 11, 12, and 13 were collected from various parts of the same exposure. Even where these samples are grouped into the gross size fractions (gravel, sand, and silt-clay) there is much variation among them. Any attempt to distinguish significant variations over the areal extent of the individual deposits would require analysis of either an exorbitant number of small samples or a moderate number of samples of excessive size, i.e. a ton each. On Figure 17 the results of the mechanical analyses are plotted in order of increasing distance from the apex of the Rocky Hollow and Buck Run fans. There appears to be no systematic overall variation larger than the variation within one exposure. On the other hand, visual estimates of the largest boulders present indicate decrease in size away from the apex.

Rounding

Field estimates of roundness of pebbles and cobbles were made by visual comparison with the silhouetted figures of Krumbein (1941a). As

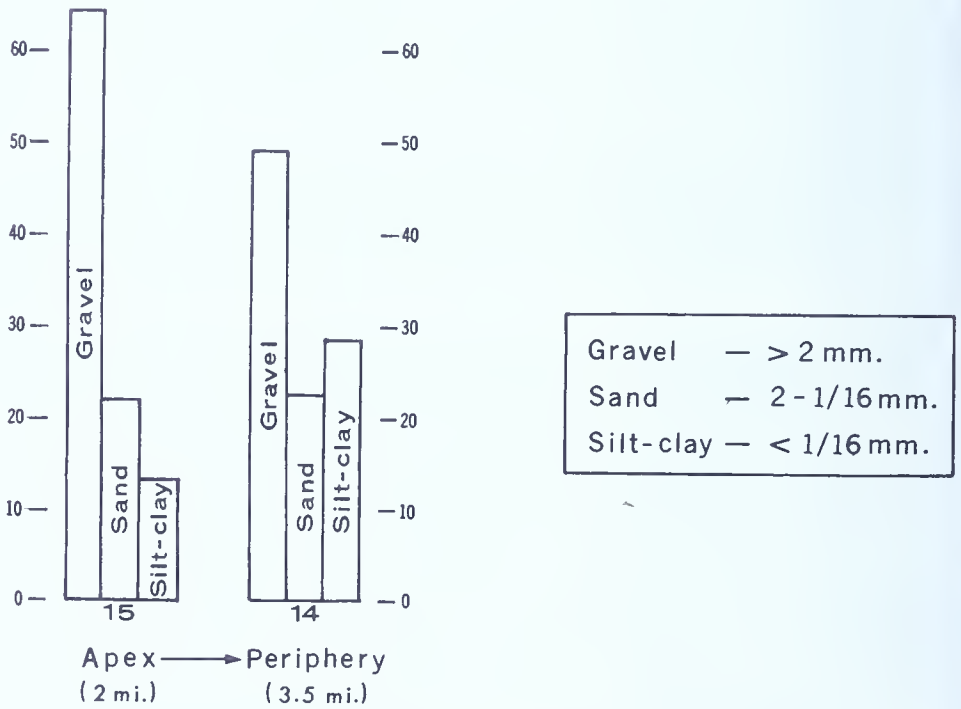
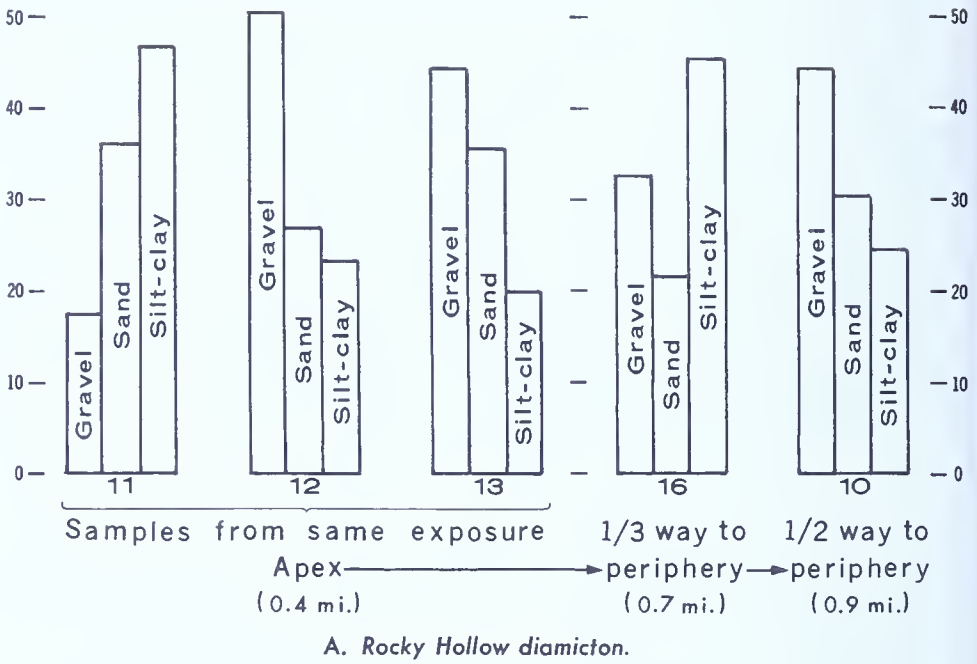


FIGURE 17. Frequency histograms of roundstone diamicton. Locations given from apex to periphery of fans. Note that variation within one exposure (samples No. 11, 12, and 13) is as great as the areal variation within the fans. Distance from probable source of roundstones is given in parentheses.

shown by Table 1, averaged roundness values for the size ranges 32 to 64mm and 64 to 128mm systematically increase with distance from the diamicton fan apices. The rate of increase in rounding with distance for the diamicton clasts is equal to or greater than that found by Krumbein (1940, Fig. 6; 1942, Fig. 14) for flood deposits in southern California, and slightly less than that determined in tumbling barrel experiments by Krumbein (1941b, Fig. 2).

Table 1—*Average roundness of sized clasts in two roundstone diamictons. Note increase in roundness within a given size range in the direction of the fan periphery. (Estimates made in the field by visual comparison to silhouetted figures given in Krumbein (1941). Scale from 1 to 10 in order of increasing roundness.)*

Location (distance from source area in parenthesis)	Sample number	Size range 64 to 128 mm		Size range 32 to 64mm	
		Average roundness	No. of clasts measured	Average roundness	No. of clasts measured
Rocky Hollow diamicton					
Apex (0.4 mi.)	11	—	(—)	3.2	(11)
	12	3.0	(7)	3.4	(50)
	13	2.0	(21)	2.6	(54)
One-half way to periphery (0.7 mi.)	16	2.75	(8)	3.5	(41)
One-half way to periphery (0.9 mi.)	10	4.3	(10)	3.5	(34)
Buck Run diamicton					
Near Apex (2 mi.)	15a	3.4	(12)	3.2	(93)
Periphery (3.5 mi.)	14	5.2	(9)	4.8	(66)

Lithologic analyses of the roundstones

Roundstone counts indicate that some bedrock units contribute more clasts than others. As expected, the most resistant rocks are generally most concentrated in the diamicton, especially in the outer parts of the fans. Fragments of surficial iron ore occur locally in the diamicton.

Near the periphery, in a given exposure, distribution of clasts appears to be homogeneous. At the apex of the Rocky Run diamicton, roundstone counts made on different parts of the same exposure show a wide variation in formational derivation of the clasts (Table 2), indicating that mixing of materials was not complete. This suggests that near the fan apex bedrock ridges on both sides of the water gap contributed unmixed debris by some process of mass movement. The absence of "iron" sandstone from these counts furnishes some support for this suggestion, for "iron" sandstone crops out within Rocky Hollow but not on the slopes bordering the water gap. Roundstones of "iron" sandstone do not occur on parts of the fan apex (Table 2), but are present near the fan periphery (Table 2).

Table 2—*Provenance of clasts from apex to periphery of two diamicton fans. Only clasts with diameters between 32 and 64 mm were tabulated.*

<i>Formational source of clasts in percent of total</i>	<i>Rocky Hollow diamicton</i>					<i>Buck Run diamicton</i>	
	<i>Apex</i>			<i>Half way to periphery</i>	<i>Periphery</i>	<i>Near apex</i>	<i>Periphery</i>
	<i># 11</i>	<i># 12</i>	<i># 13</i>	<i># 16</i>	<i># 10</i>	<i># 15a</i>	<i># 14</i>
Tuscarora Sandstone	45	7	11	61	84	79	45
"Iron Sandstone"	—	—	—	7	10	1	25
Juniata Sandstone	19	24	44	22	3	18	3
Bald Eagle Sandstone	—	44	39	10	—	2	—
Reedsville and Rose Hill shale, siltstone and sandstone	36	25	6	—	3	1	27
Total number of clasts in sample	11	57	54	41	32	91	69

Fabric analyses

From each of five exposures approximately 100 roundstones were oriented in the field for fabric determinations. The projections of the long and short axes were plotted on the lower hemisphere of an equal-area net. A definite orientation of both axes is apparent. Sample contour diagrams drawn on the areal distribution of these points are shown in Figure 18. The azimuth and dip of the long and short axes for six localities are plotted on the surficial geology map (Pl. 3). Orientation of the long axes is highly variable; some are inclined upstream toward the fan apex as might be expected, but others are at right angles. Sample No. 14 displays a long-axes fabric perpendicular to that of No. 20 (Fig. 18), yet these two localities are only 500 feet apart on the perimeter of the Buck Run fan. The short axes tend to show an upstream imbrication of 10 to 20 degrees.

Appearance under the microscope

Thin sections of the impregnated matrix of roundstone diamicton show subangular quartz-sand grains in a matrix of clay. At the apex of the Rocky Hollow diamicton, the quartz grains have undergone almost no additional rounding as compared with the parent Paleozoic rocks. Although many of the sand grains touch each other, the peripheries of most of the grains are completely bordered by clay. Some thin sections show weathered shale pebbles that have sharp, optically distinct contacts with the clay matrix.

X-ray analyses of clays

Seven samples of the clay matrix of the diamicton were taken from suspension, dried on a glass slide and X-rayed by a Phillips diffractometer. The most abundant clay mineral is illite, which constitutes about 50 to 70 percent of the clay. The remainder consists of kaolinite and chlorite;

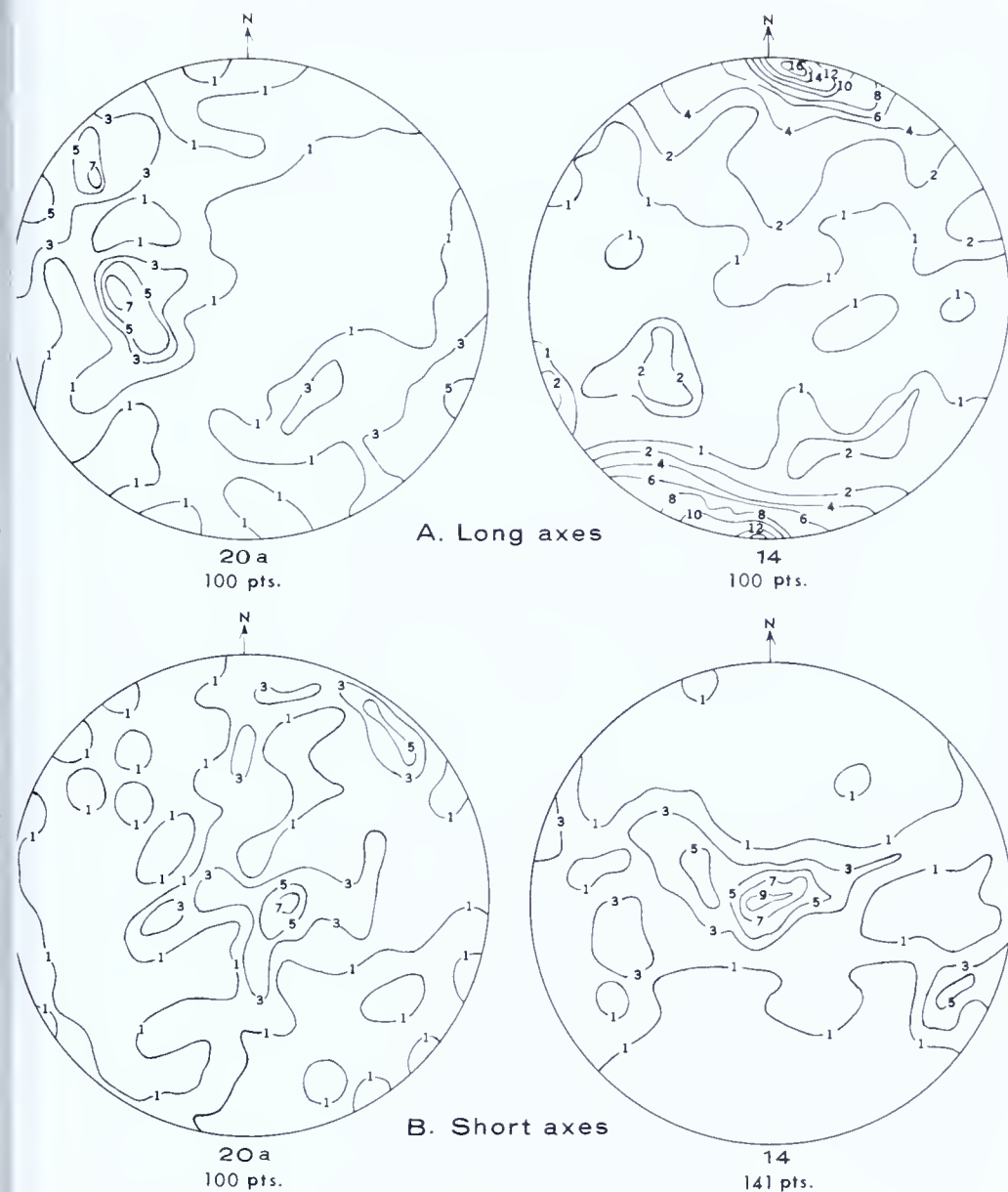


FIGURE 18. Orientation of long and short axes of roundstones in diamicton. Contours on number of points in a one percent area. A—Long axes, B—Short axes.

no montmorillonite was noted. The presence of illite with lesser amounts of kaolinite is what one might expect to find in a local modern soil (Grim, 1953, p. 337-341).

Relation to other deposits in the Appalachians

Accumulations of roundstone diamicton similar to those described in this report are widespread in the Appalachians. Although many geologists are aware of the existence of this material, few descriptions are published. Similar deposits occur in the Amberson Valley to the north-

west along the Pennsylvania Turnpike, and in the limestone valleys along Nittany arch. Ten miles south of the mapped area, Sando (1957, Pl. 2) mapped lobes of "mountain wash" which extend along the streams draining east into the Cumberland Valley. J. T. Hack (personal communication, 1962) mapped a roundstone diamicton in the Shenandoah Valley, Virginia (Fig. 13). Miller and Fuller (1954) mapped similar deposits in southwesternmost Virginia as alluvial fans. Near Elkton, Virginia (King, 1950) and in the northeasternmost Tennessee (King and Ferguson, 1960), P. B. King described exposures of gravel (diamicton of this report) that truncates older, early Tertiary(?), surficial deposits or iron ore, manganese oxide, residual clay and lignite. These accumulations occur in valley terraces on the lower flanks of high ridges, and overlie what has been called the Harrisburg erosion surface. Neuman and Wilson (1960) mapped similar materials in the Blockhouse quadrangle in northeastern Tennessee.

Comparison to modern alluvium

What is the relation between the diamicton and the local alluvium? Surficial deposits clearly recognizable as alluvium are present along all streams in this area. In texture the alluvium ranges from gravel to mud. Descriptions of two exposures are given here because they bear directly on the origin of the diamicton.

Fresh and partially weathered alluvial gravel are well displayed along Buck Run one mile northwest of Dickey. The modern channel is paved with well-rounded, imbricated roundstones. Between the roundstones is a matrix of *shale chips*, sand, silt, and clay. Presumably the roundstones are moved only during floods; the silt-clay fraction is deposited between the roundstones at times or in locations of slower currents. It is virtually impossible to deposit the silt-clay and roundstones simultaneously at the same place.

Alluvial gravel crops out in the creek bank. An immature soil has developed on this gravel. The following section is exposed:

<i>Depth</i>	<i>Description</i>
<i>(feet)</i>	
Top	Grass on surface
0-0.1	Organic soil
0.1-1	Gravel or diamicton, dusky-yellow, imbricated. The matrix contains more clay than the matrix in channel bottom, but not nearly as much as the roundstone diamicton at Mercersburg. The shale chips are deeply weathered. This is the B-horizon of the modern soil.
1-2	Silt, sandy, yellowish-gray.
2-4	Gravel, yellowish-gray, imbricated, in loose sandy matrix with many open cavities. Except for minor clay coating, this zone shows little effect of weathering.

Thus clay can be introduced into an alluvial gravel either by deposition within the gravel at times of low-velocity currents or by transport down into the gravel by normal soil-forming processes. In the creek-bank exposure the gravel is obviously alluvial; only one foot of gravel is notably clayey, and this zone still shows imbricate structure. But upon examination of this exposure, it seems quite probable that if the weathering were assumed to be ten times more intense or protracted, a deposit similar to the roundstone diamicton could be produced.

Another critical exposure of alluvial gravel occurs across the Cumberland Valley, where the main branch of Conococheague Creek flows from South Mountain into the Cumberland Valley. In excavations at the Mount Cydonia Sand Company Quarry No. 2, yellowish-gray gravel with imbricate structure is exposed at the level of the modern drainage. The matrix is loose unconsolidated sand with little silt or clay. Although most of the roundstones are light-brown or dusky-blue quartzite, 25 percent are volcanic rocks derived from South Mountain. The volcanic roundstones are fresh, commonly having polished surfaces and hard crystalline interiors. No roundstones of volcanic rocks now occur in the nearby roundstone diamicton (as noted earlier under "other exposures in the Cumberland Valley"). Yet volcanic roundstones should have been deposited in the original sediment, for they have the same source area as does the dusky-blue quartzite present in both diamicton and gravel. Evidently the diamicton originally contained volcanic rocks, but these immature clasts were destroyed subsequently by weathering.

Origin

The diamicton fans described in this report were previously considered alluvial gravel, primarily because they contain obviously transported roundstones and are located near modern stream courses (Stose, 1909, p. 12). Upon closer examination it is apparent that the diamicton has other characteristics which an unaltered alluvial gravel normally lacks. Sorting and well-defined stratification and imbrication, all of which are normally present in alluvial gravels, are not present in the diamicton. These characteristics could have been originally present and subsequently altered by prolonged and deep weathering. Although the present appearance of the diamicton accumulations can be explained as the result of deep weathering of alluvial gravels, it can also be attributed to transport and deposition by mudflows. The low slope of transport, presumed to be approximately the same as the present surface slope, rules out, at least for the valleyward occurrences, all mass-movement processes other than mudflow. Thus the accumulations of diamicton are either (1) mudflow sediments or (2) deeply weathered gravels secondarily enriched in clay. In the following discussion, these two hypotheses of origin are presented and evaluated in the light of the character of the diamictons. It is con-

cluded that origin through weathering of alluvial gravels is the more likely hypothesis.

Mudflows are associated commonly with arid climates (Blissenbach, 1954) but occur locally in humid-tropical (Krynine, 1936, p. 304) and humid-temperate (Crandell and Waldron, 1956) climates. If a clay-rich regolith becomes saturated with enough water, commonly by high-intensity precipitation or rapid snow melt, it will move downslope by rapid flowage. If the slope of transport decreases sufficiently, movement of the mudflow ceases and an essentially nonsorted, nonstratified sediment is formed. The presence of a dense vegetation cover inhibits the formation and downslope movement of a muddy slurry or mudflow; probably this accounts for the absence of contemporary mudflows in the central Appalachians.

Weathering of an alluvial gravel with a matrix rich in shale chips and containing roundstones of shale, dirty sandstone, and siltstone would form new clay minerals as well as release clay and silt from the constituent clasts. Clay could either remain in place, or, by normal soil-forming processes, move down into the B-horizon of the soil, where it would be left as coatings on the larger clasts. In the central U. S., calcareous Illinoian glacial outwash weathers to a diamicton which was termed pebbly gumbosand by Leighton and MacClintock (1930, p. 41). In addition, clays from the adjacent residuum might be introduced by ground water, slumping, and frost heaving. The formation of silt and clay at the expense of the larger clasts would degrade the sorting to the present nonsorted or very poorly sorted state. The poor development of stratification may indicate flood gravels; for example, flood gravels in southern California show little or no stratification (Krumbein, 1942, Pl. 4). Weathering and slumping due to solution of the underlying rocks would tend to obliterate stratification and imbrication, and disperse the clasts in the matrix. The surface of the deposit would have about the same slope as the present streams.

The prominent characteristics of the diamictons are compatible with origin either by mudflow deposition or by deep weathering of alluvial gravels. These characteristics are: (1) absence of sorting, (2) absence of well-defined stratification, (3) presence of enough silt-clay to permit the dispersed state, (4) presence on slopes that range from 0.75° to 8° , and (5) presence of roundstones.

On the other hand, some observations made on the accumulations of diamicton suggest that they are deeply weathered alluvial gravels rather than mudflow sediments. These observations, and the reasons why they favor deep weathering of alluvial gravels over mudflow sediments, are:

1. The diamictons are much poorer in immature clasts than the modern alluvium of the streams with which the diamicton fans are associated.

- The best example of this relation is on the east side of the Cumberland Valley, where one quarter of the roundstones in modern alluvium of Conococheague Creek are derived from Catoctin volcanic rocks. No volcanic rocks are recognizable in the nearby clay-rich diamicton. Gravel exposures along Buck Run display on a small scale the postulated weathering relation between alluvial gravel and diamicton. The B-horizon of a thin soil formed on the gravel is best classified as diamicton, but this sediment still shows imbricate structure, and the matrix is not as rich in clay nor as bright in color as, for example, the Mercersburg diamicton exposure. As noted earlier, a limited amount of silt and clay is also deposited within the gravel at times of low water. Shale chips are common in the gravel matrix in the channel of Buck Run, but are not as abundant in the Mercersburg diamicton exposure. If the diamicton accumulations are unaltered mudflow sediments one would expect to find immature clasts of shale and volcanic rocks, for they are present in the source area and persist even in the nearby streams. The absence or paucity of immature clasts in the diamicton bodies is readily explained as a result of their destruction by weathering in place. In the Shenandoah Valley of Virginia, John Hack (spoken communication, 1962) notes a progressive decrease in the percent of immature clasts from the lower and younger gravel terraces (diamicton accumulations) to the higher and older terraces.
2. Mudflows are generally interbedded with moderately well-sorted alluvial sediments (Blissenbach, 1954, p. 188; Bull, 1963, p. 245). Only at the Fayetteville and the Ft. Loudon Bypass localities were lenses of alluvial sand noted within the diamictons. Deep weathering of an alluvial gravel would tend to obliterate stratification and could produce rather massive deposits such as the diamictons. Weathered Illinoian outwash in the central U. S. is rather massive, similar to this diamicton. On the other hand, if the diamicton bodies were mudflow deposits one would expect them to be interbedded with alluvial deposits. Furthermore, mudflows commonly contain bubble cavities (Bull, 1963, p. 250). None were noted in the roundstone diamicton.
 3. Increase in rounding of the roundstones with distance from their source is more expectable in an alluvial gravel than in a mudflow sediment. Alluvial gravels are readily rounded, largely by abrasion of exposed surfaces of stationary roundstones in stream channels. A mudflow probably could accomplish little rounding.
 4. Diamicton is present in the middle of the Cumberland Valley on banks 50 feet above Conococheague Creek. The gradient of this stream is less than 10 feet per mile ($0^{\circ}7'$) for a distance of 5 miles upstream. This gradient is probably too low to sustain movement of a gravel-bearing mudflow. The deposit is more reasonably interpreted as allu-

vial gravel, accumulated in the same manner as modern alluvium along Conococheague Creek and then subjected to extreme weathering.

Of course it can be argued that a deeply weathered deposit of interbedded mudflow and alluvial sediments compatible with the requirements of paragraphs 1 and 2 would also look like roundstone diamicton. This is a more complex postulate and involves a phenomenon, mudflow, which has not been observed in the central Appalachians. In addition, paragraph 4 argues directly against the possibility of mudflow deposition.

There is at least one aspect of the diamictons that appears difficult to explain by the weathered gravel hypothesis. Modern alluvium is mostly silt and sand with minor lenses of gravel. Why are there almost no beds noted in the diamictons without roundstones in them? The absence of roundstone-barren beds might be explained within the weathered gravel interpretation in three ways: (1) possibly the diamicton was deposited during a rigorous climate when only gravel was deposited, (2) possibly slumping has mixed up the alluvium so that gravel-barren zones are no longer present, or (3) perhaps alluvial mud is either now weathered to material that is not distinct from the diamicton, or is mistaken for bed-rock residuum.

In this discussion it has been assumed that all the bodies of diamicton noted (Pl. 3 and Fig. 11) have the same origin. This assumption is made because the various exposures are similar in appearance and the diamicton has lateral continuity between many of the exposures. Some of the diamicton that rests on the steeper mountain slopes has probably moved downslope with the aid of sheet erosion and mass-movement processes. Probably diamicton resting on slopes of more than 10° is significantly affected by soil creep. Furthermore, as noted earlier, some of the diamicton accumulations are rather special gravels, probably having accumulated in caves.

Age

Direct evidence on the age of the diamictons is lacking. It seems likely that various parts of the accumulations were emplaced at different times within a whole spectrum of ages extending back into the Cenozoic Era. Probably most of the diamicton is of Late Cenozoic age. In the Elkton area of Virginia, King (1950, p. 62) concludes that a tier of three gravel deposits, similar to these diamictons, "were laid down during the Pleistocene, a time of climatic fluctuation, each deposit corresponding to a glacial epoch, and each time of erosion to an interglacial epoch." As lignite of Upper Cretaceous age is now present on the valley floor (Pierce, 1965), some of the diamicton could conceivably have been emplaced during Cretaceous time. Features that indicate considerable antiquity for parts of the roundstone diamicton accumulations are: (1) local

post-diamicton incision of streams to a depth of 60 feet, (2) post-diamicton carbonate solution forming ridges and sinks as much as 30 feet deep, (3) extensive weathering of some roundstones, and (4) formation of a "soil" 15 feet thick or more (provided the diamicton is the result of weathering of alluvial gravels).

If the diamicton is the product of weathering of alluvial gravels, the youngest deposits are as old as the minimum time required to weather a gravel to diamicton. The B-soil horizon of Illinoian glacial deposits shows almost the same amount of clay permeation as these diamicton deposits.

Conclusions

The fan- or lobe-shaped bodies of roundstone diamicton are interpreted as deeply weathered alluvial fans. The more linear accumulations are thought to be weathered stream-channel deposits. Many of the irregular accumulations on steep (10°) mountain slopes might best be described as weathered colluvium in which alluvial processes played a significant part.

Apparently deposition of alluvial gravel and subsequent weathering of the gravel to bright-colored accumulations of roundstone diamicton are normal events in the erosion of the given bedrock under the late Cenozoic climate. During the four or more Pleistocene glaciations, frost action in this region probably contributed much colluvium rich in rubble to the mountain streams. (See also Denny and Lyford, 1963, p. 15-17). Where they debouch from the mountains onto the valley floors, these heavily loaded streams are expected to have deposited gravel. The accumulation of alluvial gravel above carbonate bedrock—and to a lesser extent above shale bedrock—is promoted for two reasons: (1) the stream gradients above shale and carbonate bedrock are low and stream aggradation is thus encouraged, and (2) the shale and carbonate bedrock weather to residuum more erodible than the gravel in the stream channels; consequently streams over carbonate and shale bedrock are expected to migrate laterally and leave behind gravel. In addition, once gravel is deposited above carbonate bedrock it will not be subject to subsequent vigorous surficial erosion. Subterranean solution of the underlying carbonate rocks will result in lowering of the surficial materials above the bedrock without surficial erosion. Roundstones deposited above these dissolving carbonate rocks will be lowered as though they were on a slowly descending elevator. Also, roundstones deposited above shale or carbonate rock will retard surficial erosion. The roundstone-capped areas will be eroded less rapidly than uncapped areas, and in time will rise above them. Extended retardation of surficial erosion while chemical weathering continued accounts for local deep weathering of shale beneath thin roundstone diamicton and for thick accumulation of carbonate residuum beneath a capping of roundstones.

TOPOGRAPHY

Erosion within the McConnellsburg quadrangle has removed the less resistant rocks to form valleys at altitudes of 500 to 1,000 feet, and has left the most resistant rocks to uphold long, even-crested ridges at altitudes of about 2,000 feet. Tuscarora Sandstone generally forms the ridge crests; limestone and shale form the valleys. Figure 19 shows three major features of the topography within the quadrangle: (1) areal distribution of altitudes, (2) general altitudes of the Kittatinny, Harrisburg, and Somerville topographic surfaces, and (3) a visual estimate of the surficial distribution of sandstone, shale and carbonate rocks with altitude.

WEATHERING AND TOPOGRAPHY

Weathering of bedrock and the kind of regolith thereby formed determine the erodibility of the land, thus directly affecting the development of topography. Following are short descriptions of the ways in which carbonate rock, shale, and sandstone within the quadrangle are affected by weathering and of the character of the residuum they form.

Carbonate Rock

In a humid-temperature climate, weathering of carbonate rocks involves primarily the solution of calcium and magnesium carbonate by acidic ground and surface waters. Insoluble materials (chert, clay, and quartz sand) are left behind to form poorly sorted, clayey residuum. Complete oxidation of iron compounds colors the residuum reddish brown. As the underlying carbonate rocks are dissolved away, the residuum is slowly lowered. It is eroded by rapidly flowing surface and ground waters. The cherty Beekmantown dolostone and Conococheague Formation, the Gatesburg dolomitic sandstone, and the argillaceous Chambersburg limestone are rich in insoluble debris and leave a thick residuum, which forms topographic highs relative to the lowlands of sinks underlain by the purer Saint Paul limestone. Deep percolation of acidic waters from the mountains usually forms a thick carbonate residuum at their bases. In places, a resistant surficial mantle of either roundstone diamicton or chert rubble retards surficial erosion and permits accumulation of a thick residuum. Dolostone seems to be more resistant to weathering and to crop out more commonly than limestone does. Some beds of carbonate rock crop out in one place, but along strike in a similar topographic position the same beds are covered by a deep residuum. This suggests that an outcropping bed is dissolved at a rate slower or equal to that at which the general surface is eroded and thus this part of the bed continues to crop out, but that part of the same bed that is covered by a water-holding blanket of residuum is dissolved at a rate as rapid or more rapid than that at which the residuum is eroded and thus *continues* to be mantled by its own residuum.

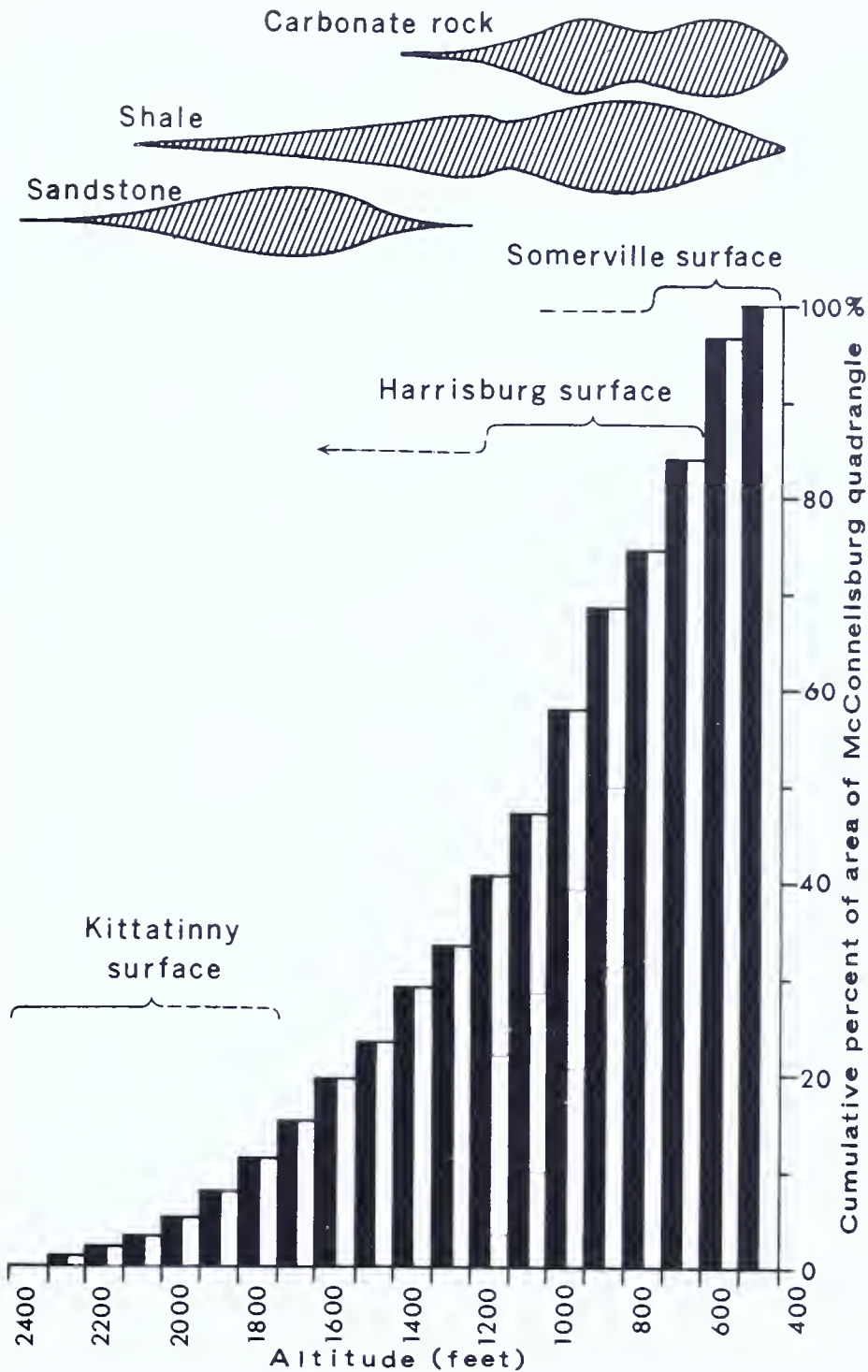


FIGURE 19. Graph of (1) areal distribution of altitudes, (2) the general altitude of the Kittatinny, Harrisburg, and Somerville surfaces, and (3) a visual estimate of the surficial distribution of sandstone, shale, and carbonate rock with altitude in the McConnellsburg quadrangle. Note: the area is split into two major drainage basins. The floor of McConnellsburg Cove lies at about 900 feet; the floor of the Mercersburg reentrant lies at about 600 feet. A frequency histogram (not included) shows a minimum at about 850 feet.

In general, carbonate rocks are reduced to a gently undulating surface, having an overall slope toward the axial drainage of 1° to 3° , but locally having slopes steeper than 10° . Near mountains, where the carbonate bedrock is mantled by roundstone diamicton, the overall slope is about 5° to 10° with local slopes as steep as 25° . The Somerville surface or "partial peneplain" is represented by lowlands on limestone below the level of the Harrisburg surface on shale.

For Nittany Valley, 75 miles northwest of McConnellsburg, the present rate of erosion of carbonate rocks was determined by Ewing (1885, p. 31) to be one foot in 9,000 years (about 110 feet per million years).

Shale

Shale weathers to a yellowish-brown clayey residuum. In contrast with carbonate rocks, the volume of shale residuum is approximately the same as that of the original bedrock. Soluble constituents, such as calcite and leachable ions, are removed. Iron compounds are fully oxidized to yellowish-brown limonite. The concentration of most elements changes by less than 10 percent from fresh to weathered shale (Calver and others, 1961, p. 69). Quartz silt constitutes about one third of the shale and residuum; probably it is relatively inert during chemical weathering. Locally either sandstone rubble or roundstone diamicton mantles the shale, protecting it from surficial erosion and, where the mantle is thick enough, from chemical weathering. Egg-shaped pods of relatively fresh shale one to 3 feet in diameter surrounded by weathered shale are exposed commonly in artificial cuts. Structures of the shale bedrock (bedding, cleavage, and joints) are preserved at about their original attitude by the residuum beneath the upper few feet of soil.

As exemplified by the shale ridge south of Fort Loudon (Pl. 1), the Reedsville shale forms a bench of rolling hills about 100 feet above the adjacent limestone lowlands in the Mercersburg reentrant. The surface, defined by the rather flat hill crests, is commonly referred to the Harrisburg "partial peneplain." Where shale underlies mountain flanks not extensively covered by sandstone debris, it forms an irregular surface having an overall slope of 5 to 10 degrees valleyward; nearer the ridge crests where mantled by more sandstone debris, the slope of the surface increases to 10 to 15 degrees. In places, sides of gullies seemingly cut below the Harrisburg surface slope 30 degrees.

The Rose Hill Formation underlies high mountain valleys where topography and altitude are largely controlled by nearby sandstone ridges and the debris eroded from them.

The Upper Devonian shales and sandstones underlie terrain characterized by shale valleys and discontinuous ridges of sandstone 100 to 200 feet high.

Sandstone

Sandstone weathers by separation along joint- and bedding planes into blocks, and by disaggregation into sand. Physical weathering, especially frost action, is responsible for separation into blocks. Under a humid-temperate climate, chemical weathering readily loosens the clay and iron-oxide cement in the Bald Eagle and lower Juniata Sandstones, but has much less affect on the silica cement in the upper Juniata and Tuscarora Sandstones. Consequently the silica-cemented, quartzose Tuscarora and upper Juniata form ridge crests about 1,000 feet above the valleys. Resistant blocks from Tuscarora and upper Juniata Sandstone cover most of the mountain slopes (see "Transported Angular Regolith").

The Bald Eagle and lower Juniata Sandstones form an irregular surface, which slopes 10 to 20 degrees toward the axial drainage. Higher up the ridges, the upper Juniata and Tuscarora Sandstones form a rather smooth surface, which slopes 20 to 30 degrees toward the axial drainage. Nearly level ridge crests of Tuscarora Sandstone represent the Kittatinny surface or "peneplain."

EFFECT OF BEDROCK STRUCTURE ON TOPOGRAPHY

Ridges and Valleys

The Paleozoic section of the Valley and Ridge province consists of formations that differ greatly in resistance to erosion. In contrast, the individual formations are remarkably constant in character and resistance to erosion over large areas. Consequently structural features such as folds, changes of dip, and cross faults are clearly reflected in the topography. Since the work of H. D. Rogers (1858), major forms such as homoclinal ridges, synclinal mountains, and anticlinal valleys have been well understood. H. D. Rogers also demonstrated that the gentler the dip of a resistant unit, the higher the ridge it forms. This relationship is well illustrated within the quadrangle by Big Mountain, the highest point within 25 miles; this mountain summit is underlain by horizontal Tuscarora Sandstone on the crest of an anticline. Within the quadrangle, ridges stand 900 to 1,800 feet above the axial drainage and are upheld by Tuscarora Sandstone dipping generally 20° to 40°. In places such as Jordans Knob, Parnell Knob (east of the quadrangle), and the Bear Lick part of Cove Mountain, two ridges of Tuscarora Sandstone converge along a synclinal axis to form a single high ridge buttressed by Tuscarora Sandstone and crested by the thinner, though resistant, Keefer Sandstone of the Mifflintown Formation and the "iron" sandstones of the Rose Hill Formation.

In general the ridges of Tuscarora Sandstone rise about 800 feet above the *mountainward margin* of the sloping valley floors. The ridge crests

appear to rise and descend parallel to the direction of drainage, although in many places this relation is nullified because the axial streams on the two sides of a ridge flow in opposite directions.

In the northern part of the quadrangle the axial streams present an interesting pattern. From east to west across the quadrangle, Broad Run flows south, Conodoguinet Creek flows north, West Branch flows south, Aughwick Creek flows north, and Cove Creek flows south. This relation is predictable upon consideration of the structure. The streams in synclines are consequent and flow north down the local plunge; the streams in breached anticlines are subsequent and flow south because they originally breached the anticlines at structurally high positions and then worked their way headward toward the north, down the plunge.

Gaps and Sags

Most gaps and sags in the ridge crests are related to observed structures, but in some places structural explanations for them are not apparent. Cross faults are not everywhere accompanied by marked sags in the ridge crests.

Although three local streams flow through water gaps in the ridges, no water gaps of major cross-axial drainage occur in the area.

Little Scrub Ridge

Little Scrub Ridge is low and irregular compared with the other ridges of Tuscarora Sandstone. Along the ridge crest at distances of 1,000 feet or so are sags 50 to 500 feet deep. These sags reflect the equally numerous cross faults shown in Plate 1. In the deeper sags the Tuscarora Sandstone is faulted out and the ridge crest is underlain by the less resistant Juniata Sandstone or Bald Eagle Sandstone. In the lesser sags the Tuscarora Sandstone is thinned by faulting. The presence of less resistant rocks beneath the ridge crest appears to be more responsible for the sags than does weakening of the rocks by faulting.

Cowan Gap

An oblique-slip cross fault trends through the north side of Cowan Gap (Pl. 1). The gap is 700 feet deep where the Tuscarora Sandstone is faulted out and the Rose Hill shale is brought against Reedsville shale. The bottom of the gap is now upheld by the thin but resistant Keefer Sandstone and Center "iron" Sandstone Members. The gap, now dry, is a site for future capture of Aughwick Creek by the stream that flows east from the gap into West Branch. The latter stream has the advantage of a gradient 25 times steeper than that of the lower course of Aughwick Creek.

Cove Gap

At Cove Gap just south of the quadrangle, Buck Run cuts through Cove Mountain, forming a notch 800 feet deep. Strikes and dips of beds near the Tuscarora-Juniata contact, located on both sides of the gap, project into each other (mapped on aerial photographs, scale 1:20,000). Fault offset, if any, does not exceed 100 feet. Nevertheless, exposures of sandstone beds within the gap display slickensiding on joint surfaces, and dip measurements indicate that a flexure or cross fold occurs near the gap. In addition, the higher part of the gap cuts through the strongly overturned and hence weakened limb of a syncline. Whether or not a mappable fault is present, structural evidence indicates weakening of the rock, which apparently accounts for the location of the gap.

Township Run Gap

The water gap where Township Run flows between Cove Mountain and Hogback Mountain is occupied by a cross fault. The fault places shale against sandstone and thus has broken the continuity of the resistant barrier of Tuscarora Sandstone. The effect of the fault in weakening the resistance to erosion of the Tuscarora and Juniata Sandstone is not known. Probably a stream cut the gap in the following sequence: (1) downward erosion in the Rose Hill Shale north of the fault until the Tuscarora Sandstone was encountered; (2) migration of the stream down the southerly plunge, across the fault and off the Tuscarora Sandstone onto Reedsville shale, and (3) continued downward erosion in the Reedsville shale.

Faults without marked gaps

Near Bear Lick, Jordans Knob, Buchanan Summit, and the head of Aughwick Creek, cross faults are reflected by sags less than 100 feet deep along the ridge crests (Pl. 1). These faults hardly offset the formation contacts. Only a minor reduction of the resistance to erosion of the ridge-forming sandstone results from these fractures, as reflected by the slightness of the sags.

Rocky Hollow

In the Rocky Hollow water gap through Cove Mountain, no evidence of localized structural weakening was observed. On both sides of the gap the Tuscarora-Juniata contact was mapped; offset, if any, was determined to be less than 10 feet. No features indicating weakening of the Tuscarora Sandstone were observed. The watershed of Rocky Hollow above the gap is less than one square mile; yet this little stream has cut a gap through apparently unweakened Tuscarora Sandstone.

A locally superposed stream

Northwest of Cape Horn, Township Run swings north and cuts across the Tuscarora Sandstone, then flows for 1,000 feet in a channel near the Tuscarora-Juniata contact, then swings east and cuts back through the Tuscarora Sandstone, and finally continues eastward through a water gap between Cove and Hogback Mountains (Pl. 1). Probably local superposition from a valley fill several hundred feet above the present stream accounts for the course of Township Run twice through the resistant Tuscarora Sandstone. Superposition must have occurred within the present valley of Township Run, for the Tuscarora Sandstone, onto which the stream appears to be superposed was not exposed until two-thirds of the present valley had been cut. Fill terraces of rubble about 50 feet above the present stream indicate local filling; superposition could have been from this or similar valley fills.

If the whole topography were eroded 1,000 feet deeper than at present, the course of Township Run would be a geologic curiosity—it would flow through a gap in a high ridge into a breached anticline, and would shortly cut right back through the same ridge. Observers might then postulate various complicated explanations for this strange course, such as regional superposition or the presence of cross faults; as viewed in its present development, the course of Township Run probably results from local superposition.

Cross folds

Along the ridge crests, cross folds represented by changes in strike of 20° to 40° correlate with sags 50 to 150 feet deep. Pronounced cross folds with accompanying sags are located along Cove Mountain 3 miles north of Tuscarora Summit, and 0.6 mile northeast of Buchanan Summit; smaller cross folds appear to be associated with many of the lesser sags (Pl. 1). The limbs of the folds uphold the high places whereas the axes of the folds, probably the loci of maximum bending, underlie the sags.

Joints and elevation of ridge crests

Variations by a factor of two in the spacing of joints, and consequently in resistance to weathering, were shown by H. D. Thompson (1949, p. 58) to correlate with highs and gaps along ridge crests. Within the quadrangle an attempt was made to measure the spacing of cross joints along ridge crests and within gaps. However, no conclusions were reached, for the following reasons: (1) exposures in the bottoms of gaps and sags are almost nonexistent, (2) rocks that crop out along ridge crests probably have fewer joints than rocks that do not crop out, and (3) the spacing of clearly visible joints changes by as much as a factor of two vertically within one high outcrop. The artificial, glacial, and stream-channel ex-

posures used by Thompson (p. 58) permitted a more valid analysis of the correlation of joint spacing with altitude than is possible in the McConnellsburg quadrangle. Cross folds, cross faults, and increases in folding probably correlate with closer spacing of joints; consequently it is expected that joints are more closely spaced in the sags and gaps previously discussed than along the higher, less deformed parts of the ridges.

TOPOGRAPHIC SURFACES

Topographic surfaces, including the Kittatinny (Schooley?), Harrisburg, and Somerville surfaces or "peneplains," occur within the quadrangle. The origin of these surfaces continues to be the subject of much controversy. Some have held that the surfaces represent several cycles of erosion and uplift, and thus that the present landscape reveals part of its history (Davis, 1889). Others have maintained that the surfaces represent simply the normal topography developed during single-cycle erosion on bedrock of the given stratigraphy and structure, and therefore consider the peneplan hypothesis unnecessary (Hack, 1960).

Kittatinny Surface

The crests of most ridges are knife-edged and remarkably level at altitudes of 1,750 to 2,100 feet. The levelness and approximate concordance in altitude of the various ridges have been interpreted to imply that the ridge crests are remnants of an ancient erosion surface named the Kittatinny peneplain, and commonly correlated with the Schooley peneplain in New Jersey.

As discussed in the present paper, variations in the altitude of the ridge crests, both between the ridges and along an individual ridge, correlate with cross faults, cross folds, and angle of dip. The crests appear to slope parallel to the axial drainage and thus to be adjusted to the present pattern of drainage.

Upon a basis of rather conservative estimates of the volume of Cretaceous and Tertiary sediments of the coastal plain, E. W. Shaw (1918) calculated that, if the Kittatinny surface is a peneplain, it was completed after more than two-thirds of the coastal plain sediments were deposited. Byron Cooper (1944, p. 213-214) demonstrated that the ridge crests have been lowered considerably more than 75 feet since the formation of the present valleys. Consequently the ridge crests are not part of an actual peneplain surface. However, their evenness might still be considered as inherited from a peneplain that has been lowered about 100 feet on the resistant sandstones.

I do not consider the peneplain hypothesis necessary to explain the ridge-crest surface within the McConnellsburg quadrangle. The simplicity of the structure and the remarkably constant thickness and char-

acter of the ridge-forming sandstones could fully account for the comparative evenness of the ridges. In other parts of the Valley and Ridge province, such as the area north of Harrisburg where the Kittatinny surface is represented by separate ridges upheld by *three* different sandstones, the argument for the Kittatinny peneplain seems more convincing.

High Benches in Path Valley

On the west side of Kittatinny Mountain, sloping benches stand at altitudes of 900 to 1,100 feet. These benches were described by Stose (1909, p. 16) as terraces possibly corresponding to the Weverton peneplain. Because no roundstones are present on them the benches are probably not river-cut features. Apparently they reflect the occurrence of resistant beds of calcareous sandstone in the Reedsville Formation.

Harrisburg and Somerville Surfaces

Most of the valley floors in the Valley and Ridge province have been commonly referred to the Harrisburg and Somerville "partial peneplains." The Harrisburg surface or Chambersburg surface (Campbell, 1933, p. 557), is well exhibited by nearly flat crests of shale hills, 50 to 200 feet high, south of Fort Loudon, and by those east of Chambersburg (10 miles east of the quadrangle). The hilltops are strongly convex. The crestral areas slope less than 3° . The sides of the valleys, which according to the peneplain hypothesis are cut into the Harrisburg peneplain slope 5° to 30° , commonly being steeper than 10° . Most of the surface in the Great Valley is underlain by shale, but in places sandstone beds are present and uphold a slightly higher surface, as do the sandstone beds in the Martinsburg Formation just east of Chambersburg. The Somerville surface is represented by a lower and not commonly dissected surface, generally on limestone, a few tens of feet above the axial drainage. An example is the lowlands bordering the shale ridge south of Fort Loudon. The Harrisburg and Somerville surfaces are discussed together because (1) the Somerville surface (on limestone) is less than 100 feet below the Harrisburg surface (on shale), and (2) in places such as McConnellsburg Cove and Path Valley either they cannot be separated or the Somerville surface is not present. The only land below these surfaces consists of portions of stream channels and banks. If the valley floors represent cyclic erosion surfaces, then all the slopes graded to the valley floors, including the ridge flanks and crests, are parts of these erosion surfaces.

In the quadrangle numerous deposits of iron ore and clay occur at the level of the Harrisburg surface. Elsewhere in the Appalachians iron ore, manganese, bauxite, and Cretaceous to early Tertiary lignite are associated with this surface (Bridge, 1950, p. 183-198). Most of these deposits have been lowered through an undetermined distance by solution of the underlying carbonate rocks.

Fans and irregular patches of roundstone diamicton occur at the altitude of the Harrisburg-Somerville surface. Where the diamicton overlies shale, its deposition appears to have been preceded or accompanied by erosion and, locally, pediment formation, as beneath the Pump Run and Broad Run diamictons. Where it overlies carbonate rocks, the diamicton has been lowered by as much as 30 feet through solution of the underlying rocks. Probably because of its resistance to erosion, much of the diamicton above carbonate rocks is at the level of the Harrisburg surface. Some sandstone roundstones on the Harrisburg surface are now isolated from their source areas by open valleys, as much as 100 feet deep, that were formed after deposition of the roundstones.

It is uncertain whether the Harrisburg and Somerville surfaces represent a period or periods of base leveling that formed "partial peneplains" on shale and then on carbonate rock. The presence of iron ore, manganese, bauxite, and lignite associated with the Harrisburg surface has often been said to show that the surface is a relic of a former base-level of erosion under a climate differing from the present one (Bridge, 1950, p. 183-198; King, 1949, p. 73-93). But iron ore and manganese are now being concentrated in surficial materials (see p. 74); hence they need not signify a different climate. Deposits of lignite and bauxite above carbonate rocks must be interpreted with caution, for they may have been lowered through great distances by solution of the underlying rocks. Although I doubt the existence of a "Harrisburg partial peneplain" I think that the Harrisburg surface is more likely a cyclic erosion surface than the Kittatinny surface. Apparently the Somerville surface represents lowering, largely by solution, of the residuum-mantled surface on carbonate rocks to an altitude near the present axial drainage.

Stream Channels and Banks

Parts of the larger streams and many of the first-order streams occupy valleys incised below the Harrisburg-Somerville surface. The valley sides commonly slope up to 20° to 30° and expose fresh bedrock.

First-order valleys are commonly incised and are partly filled with discontinuous bodies of sandstone rubble. In places fill terraces of rubble occur at distances of, say, 5, 15, and 25 feet above present drainage. Apparently notching and terracing are rather recent phenomena, for earthworks associated with the early cutting of timber, 100 to 200 years ago, are cut by lesser but similar ravines, and some artifacts of early settlers are present in the lowermost fill terraces. The notching and terracing may reflect climatic variations during the Pleistocene, but they may also partly result from the activities of man, such as deforestation.

Within the quadrangle *little or no* notching and terracing is displayed along West Branch, Cove Creek and Aughwick Creek. West Branch and

Cove Creek generally flow in open valleys with wide floodplains underlain by silt. Steep slopes or creek-bank exposures of alluvium and bedrock are common along the undercut bank of West Branch, but are normally absent on the other side of the stream. About five feet of downcutting, probably resulting from deforestation and farming, is indicated by a rather constant alluvial bank along Cove Creek.

South of the quadrangle between Mercersburg and the Potomac River, West Branch is entrenched 30 to 100 feet into both limestone and shale bedrock. A rather recent change in base level seems to be indicated there.

CONCLUSIONS

Except for recent local downcutting and the entrenchment of the lower part of West Branch, the whole topography seems to be undergoing steady-state erosion, or to be in a state of "dynamic equilibrium" (Hack, 1960) with respect to the local base levels and character of the bedrock. The streams and slopes are adjusted so that downward erosion of the bedrock can proceed at a nearly uniform rate on all rock types. The close relation of most of the gaps and sags to bedrock structures supports Thompson's (1949) thesis of the origin of Appalachian drainage by headward erosion along zones of weakness. Local superposition of streams across ridges is apparently demonstrated by the course of Township Run. Before Cretaceous and early Tertiary deposits on the valley floors of the Appalachians can be used to date the topography, the amount of lowering of these deposits by solution of the underlying carbonate rocks must be carefully evaluated.

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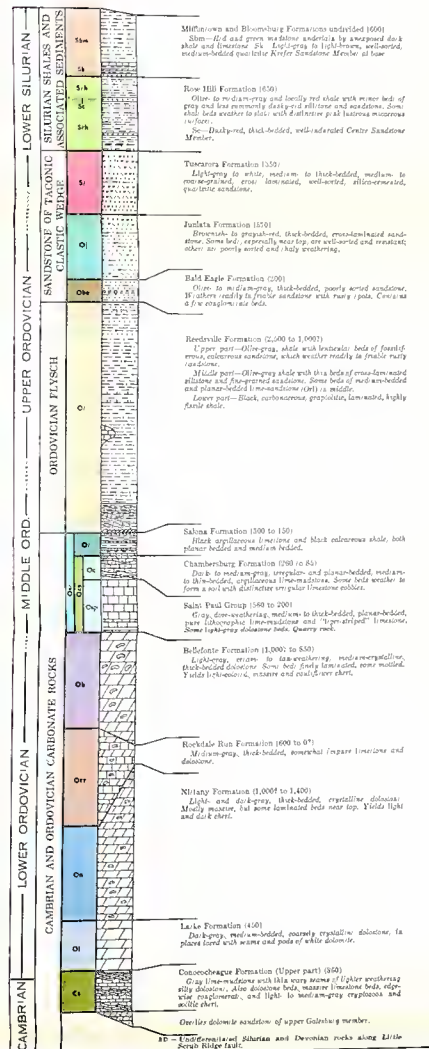
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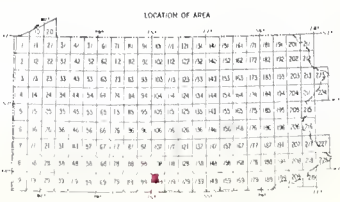
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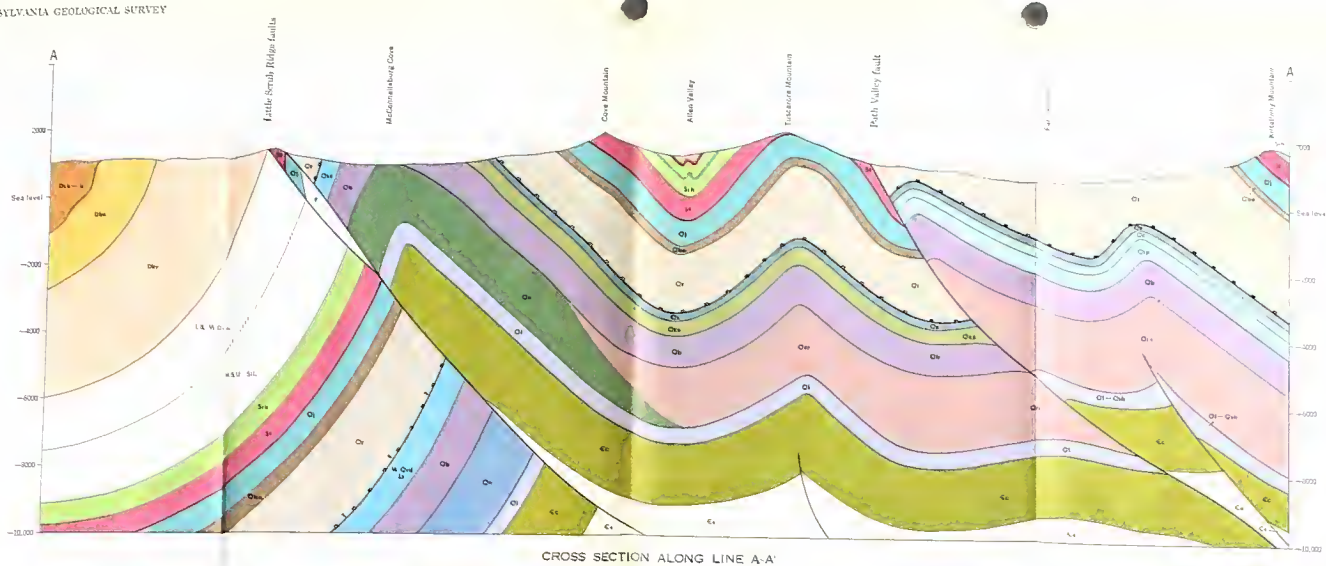
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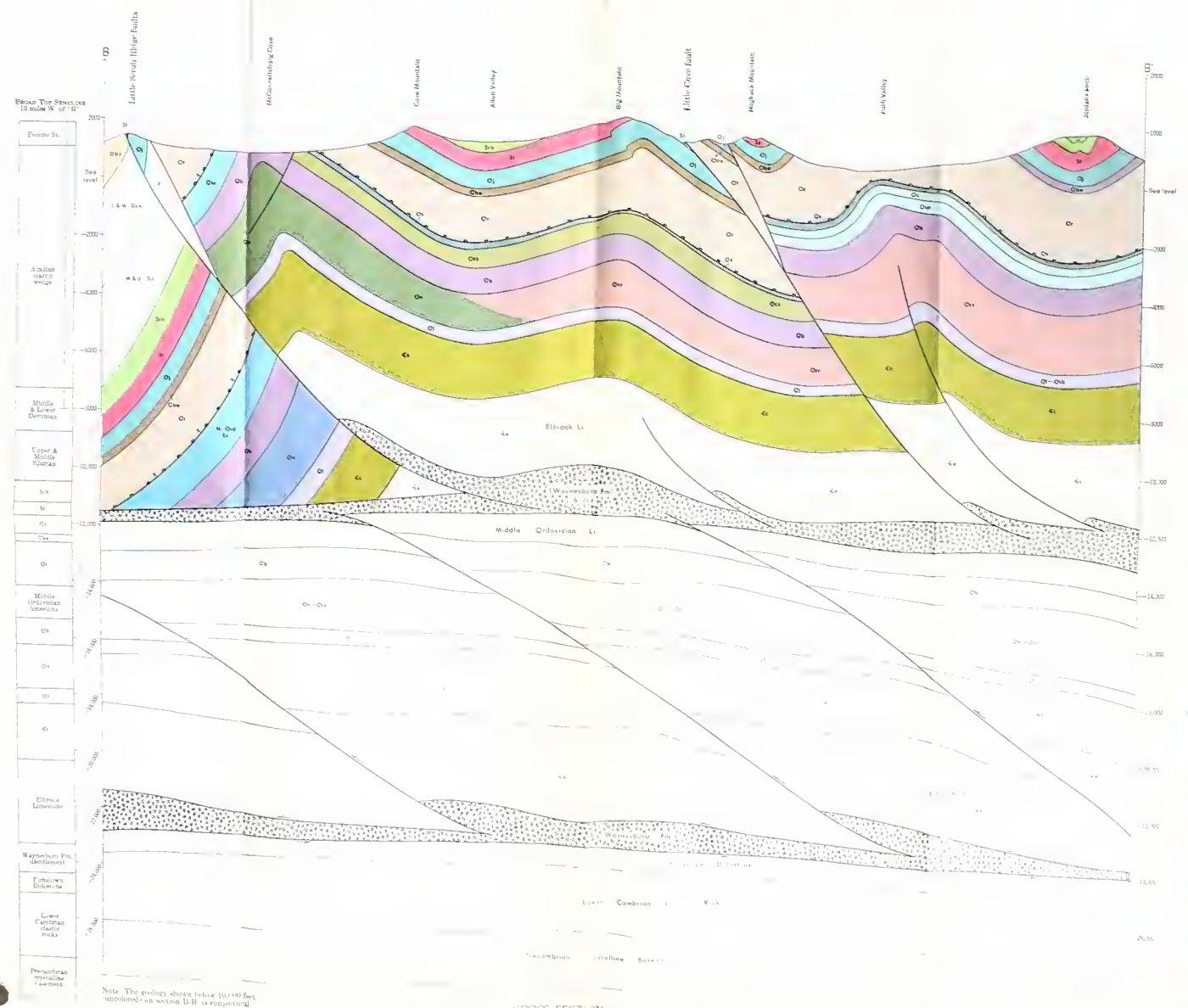


By
Kenneth L. Pierce
1966





CROSS SECTION ALONG LINE A-A'



Note: The geology shown below 10,000 feet
uncolored; an section B-B is conjectural

CROSS SECTION ALONG LINE 2-2

GEOLOGIC CROSS SECTIONS OF THE McCONNELLSBURG QUADRANGLE

By
Kenneth L. Pierce

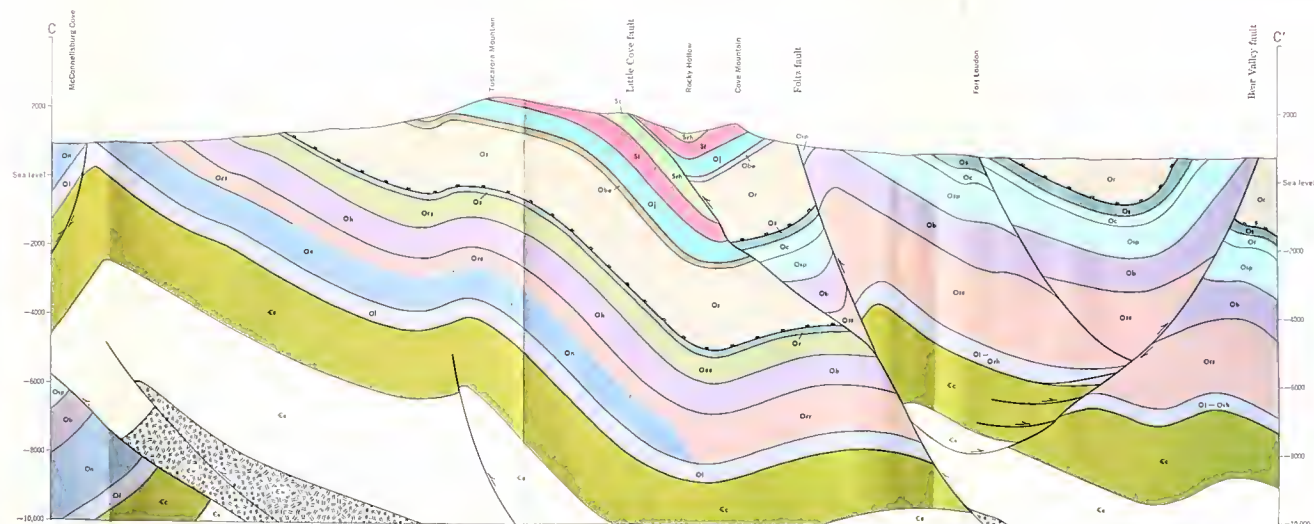
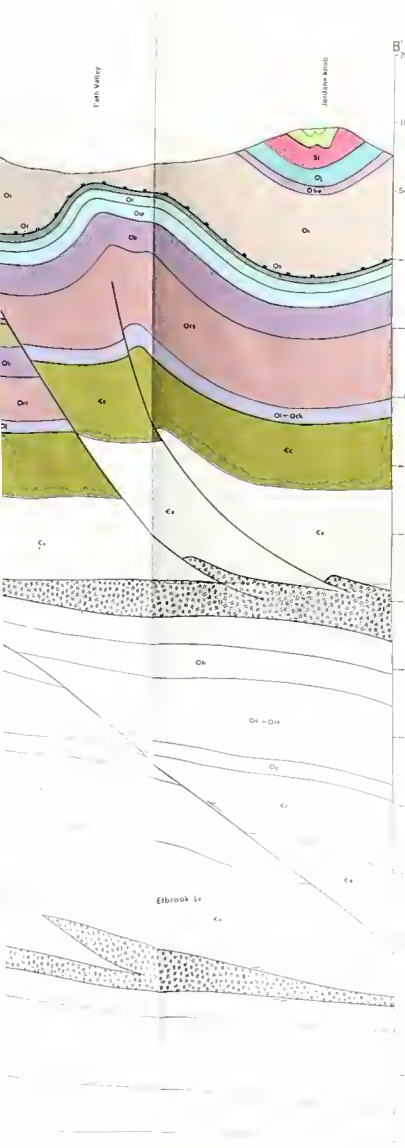
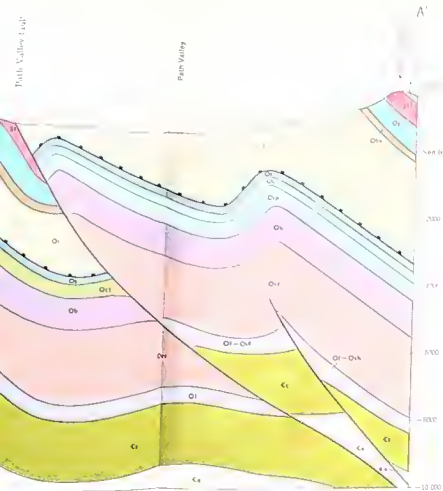
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SCALE 1:24,000

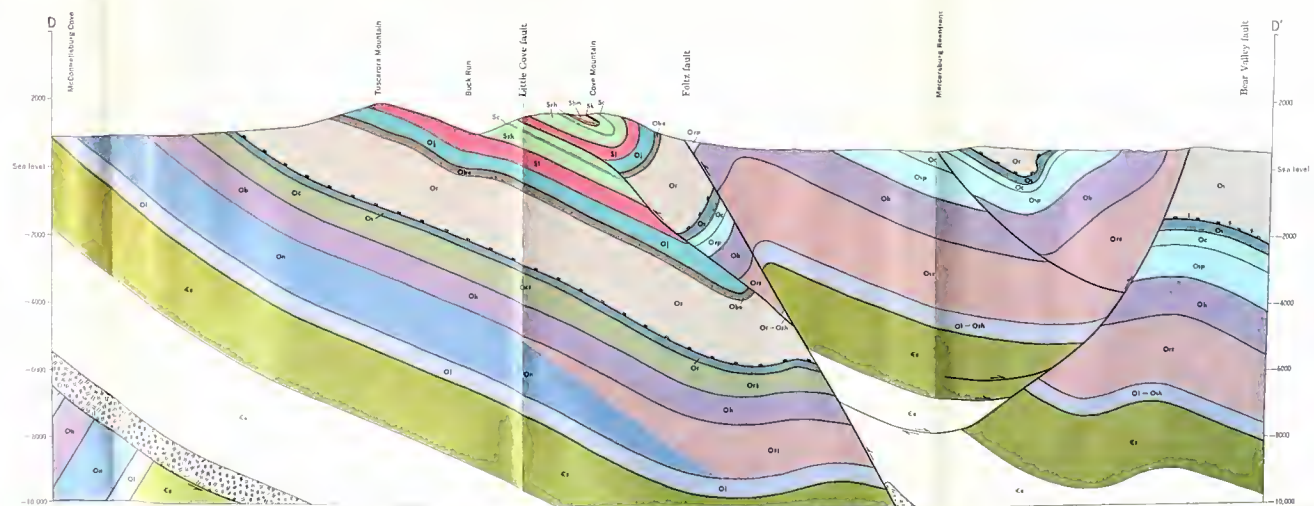
 NO VERTICAL EXAGGERATION

Symbols and colors same as used on bedrock map (Plate 1).

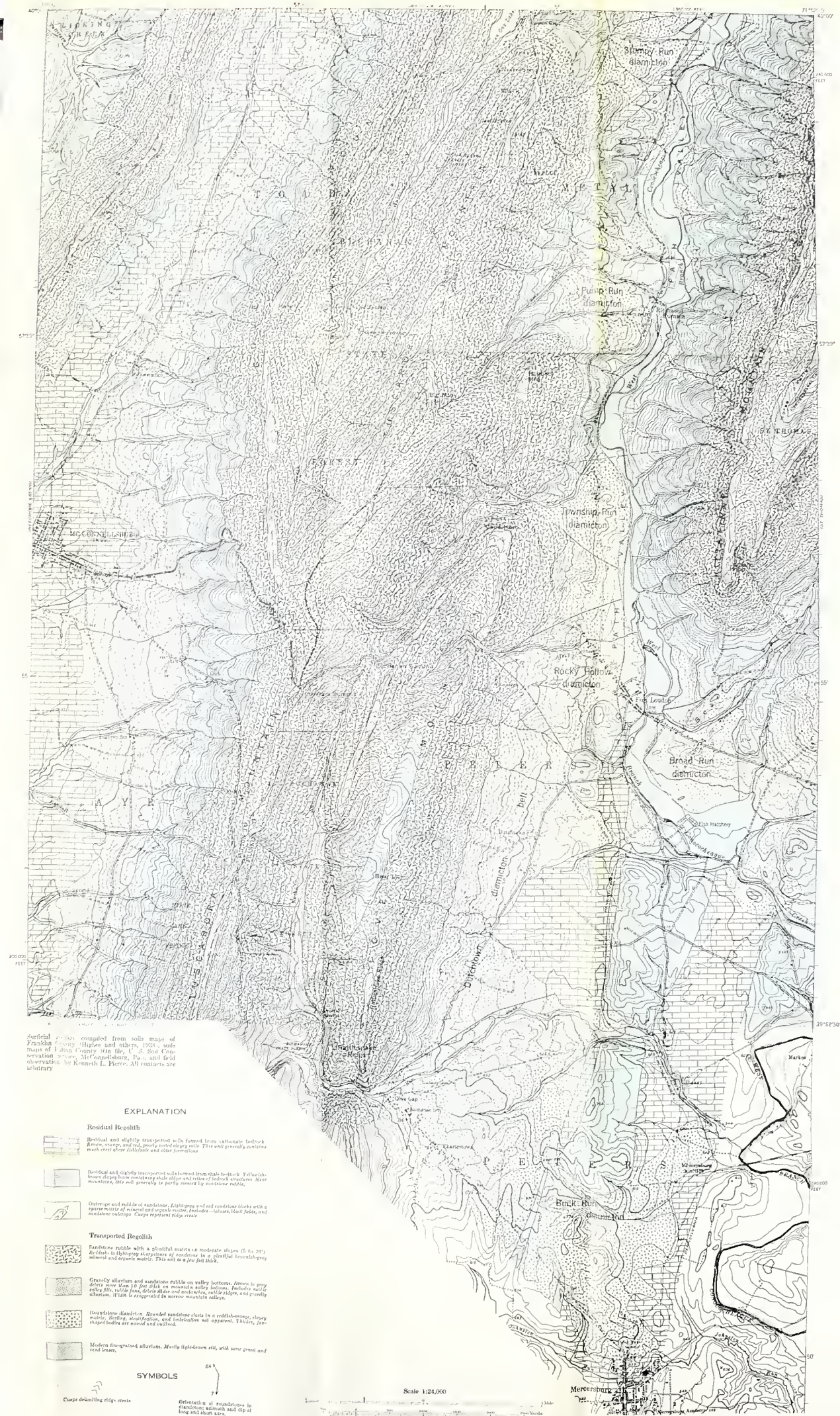
See section B-B' for names and symbols of older units.



CROSS SECTION ALONG LINE C-C'



CROSS SECTION ALONG LINE D-D'



SURFICIAL GEOLOGY OF THE McCONNELLSBURG QUADRANGLE

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